Innovative Waste Collection System: ESP32 and IoT with ML module Integration in Smart Dustbins

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Abstract— With urbanization on the rise, traditional waste management systems face unprecedented challenges. This research introduces a cutting-edge Smart Waste Management System that seamlessly integrates the Internet of Things (IoT) and Machine Learning (ML) to address these challenges and enhance overall efficiency. The system harnesses the power of IoT-enabled dustbins equipped with sensors, enabling the realtime collection and transmission of critical data to a centralized server. A sophisticated Machine Learning model, predicts dustbin fill levels based on temporal factors such as time and day, along with geographical location. This predictive modeling ensures accurate anticipation of fill levels, laying the groundwork for optimized waste collection routes. The system dynamically adapts routes based on both predicted fill levels and real-time vehicle locations, incorporating geospatial analysis for enhanced efficiency. To empower municipal authorities, a user-friendly web dashboard has been developed. This dashboard provides real-time insights into dustbin fill levels, route optimization, and other critical data, facilitating prompt decision-making. The integration of ML algorithms and IoT technologies has demonstrated significant improvements in waste management efficiency, contributing to a more sustainable urban development paradigm. Additionally, smart dustbins integrate Infrared (IR) sensors and servo motors to enhance functionality. The IR sensors are strategically positioned to detect hand motion, enabling hands-free operation and promoting hygiene. When a user approaches, the lid opens automatically, providing a convenient and touchless waste disposal experience.

Furthermore, a servo motor facilitates precise and controlled lid movement, ensuring reliable and efficient operation. The envisioned system paves the way for smarter, cleaner cities by addressing the complexities of waste management in the context of rapid urbanization, ultimately fostering urban sustainability.

Keywords- Waste Management System, IoT, Machine Learning, Sensors, Smart Dustbins, Integrated monitoring system.

I. INTRODUCTION

Urbanization brings forth unprecedented challenges, and among them, efficient waste management stands as a crucial frontier for sustainable urban development. Conventional waste collection methods are often marred by inefficiencies, contributing to increased operational costs and environmental concerns[1][2]. In response to these challenges, this work introduces a groundbreaking Smart Waste Management System that seamlessly integrates advanced technologies such as the Internet of Things (IoT) and Machine Learning (ML).

The foundation of the system lies in the deployment of smart dustbins, each equipped with cutting-edge sensors. The ultrasonic sensor serves as the primary tool for accurate measurement of dustbin fill levels, providing real-time data on the waste accumulation within. Complementing this, Infrared (IR) sensors and servo motors are strategically incorporated, transforming these smart dustbins into interactive and userfriendly solutions. The IR sensor technology introduces a touchless and hygienic approach to waste disposal. Upon detecting hand motion, the lid of the smart dustbin opens automatically, ensuring a seamless and sanitary waste disposal experience. The servo motor, responsible for lid movement, adds a layer of precision and reliability, addressing the operational challenges often associated with conventional dustbins [3].

As data flows in real time from these intelligent dustbins, a centralized server processes the information, laying the groundwork for an advanced ML model. Leveraging the power of Linear Regression, the ML model predicts dustbin fill levels based on temporal factors such as time and day, as well as geographical coordinates. This predictive analysis forms the cornerstone for the dynamic optimization of waste collection routes, ensuring that resources are allocated efficiently [4].

The amalgamation of these technologies is not merely a conceptual framework but a tangible solution that has demonstrated substantial improvements in waste management efficiency. The integration of ML algorithms enhances adaptability, allowing the system to evolve and refine its route optimization strategies based on historical data [4]. Furthermore, the user-friendly web dashboard empowers municipal authorities and waste collection teams with realtime insights, transforming decision-making processes.

This work aims to present a comprehensive exploration of the Smart Waste Management System, delving into the technical intricacies of ultrasonic and IR sensor integration, the application of ML algorithms, and the tangible benefits observed in operational efficiency. Through this innovative approach, the project envisions cleaner, smarter, and more sustainable urban environments.

II. Objectives

In this proposed work, the primary objective is to establish a comprehensive IoT and ML-based smart dustbin system to optimize waste management. The initial focus is on implementing IoT sensors on dustbins to enable real-time monitoring of fill levels, utilizing both location-aware and filllevel sensors for accurate data collection. The subsequent step
involves developing efficient data acquisition and preprocessing mechanisms, ensuring the handling of missing or noisy data, and implementing algorithms for temporal data aggregation. Feature engineering becomes crucial, involving the extraction of pertinent data such as dustbin locations, fill levels, and historical travel paths, forming the foundation for subsequent machine learning model training.

The central goal of the project is to train a machine learning model capable of predicting the shortest travel paths for municipal vans based on historical data, selecting an algorithm that appropriately addresses the spatial nature of the problem. The integration of the ML model into the system and the development of a user interface for municipal van drivers to input their location and receive dynamic, real-time path recommendations are key milestones. Additionally, the project emphasizes the establishment of a reliable database system, continuous monitoring for real-time updates, and the implementation of an alert system for timely driver notifications. Rigorous testing, scalability planning, security measures, regular maintenance, and user documentation are also integral components to ensure the successful deployment and ethical operation of the smart dustbin system.

III. Literature Review

In recent years, the development of smart dustbins has been a focal point in waste management research, showcasing innovative approaches to address challenges in urban waste collection. This literature review explores a range of studies that have contributed to the evolution of smart dustbin prototypes, examining key aspects such as sensor technologies, automation features, and real-time communication systems. Several works have delved into the integration of advanced sensors as a cornerstone of smart dustbin development. Ultrasonic sensors, as highlighted in studies [3] [5] [6] [7], play a pivotal role in detecting the level of waste inside bins. However, limitations arise as these prototypes do not incorporate automatic opening and closing mechanisms. In response to this gap, Rohit et al. [8] proposed a prototype with an automatic function facilitated by an Infrared (IR) sensor. This system includes dual dustbins, activating the second when the first reaches maximum capacity, while also integrating alert systems for timely notifications [9] [10] [11] [12].

Automation and human interaction features have been explored in smart dustbin prototypes. Anilkumar et al. [11] introduced an IR sensor for human detection, automating lid actions based on human presence. Johnson & Shyni [13] developed a comprehensive system that monitors trash levels, weight, and CO2 presence, displaying real-time information on LCD screens. The technological underpinnings of these prototypes involve a combination of IoT, wireless communication, and processing platforms. Kumar et al. [14], Rohit et al. [8], and Kariapper et al. [15] harnessed IoT, GSM/GPRS, and GPS for real-time information sharing and location tracking of dustbins. Arduino and ATmega have emerged as popular processing platforms [12][7][16], with cloud platforms such as Ubidots employed for efficient data storage [7].

Real-time location tracking algorithms have become imperative for the effective distribution of dustbins across urban landscapes. LEACH algorithm utilized by [16], Dijkstra's algorithm employed by [17] [15] and a modified Dijkstra's algorithm [17] have demonstrated effectiveness in real-time tracking of dustbin locations using GPS. Heuristic algorithms, as demonstrated by Johnson & Shyni [13], have been employed to solve tracking problem.

From the survey we have seen that, recent advancements in smart dustbin prototypes signify a convergence of sensor technologies, automation features, and real-time communication systems. These innovations not only address the efficiency of waste management but also incorporate intelligent features for human interaction and environmental monitoring. As the field progresses, there is a notable shift towards comprehensive solutions that leverage a combination of advanced technologies for sustainable urban waste management.

IV. Component Selection

For the smart dustbin system integrating IoT and ML, the key components are strategically selected to ensure seamless functionality. IoT sensors, including fill-level and locationaware sensors, constitute the foundation for real-time data acquisition. These sensors are complemented by certain development boards, such as ESP32 or ESP8266 NodeMCU to process and transmit data. A robust database system, possibly utilizing cloud services like AWS or Azure, is chosen for efficient storage and retrieval. Machine learning algorithms, specifically designed for spatial optimization, are incorporated to predict the shortest paths for municipal vans. The system's user interface is designed for simplicity and accessibility, leveraging technologies like HTML, CSS, and JavaScript. For communication, the MQTT protocol is implemented for efficient data transmission between sensors and the central server. Regular maintenance and updates are facilitated through remote monitoring capabilities. Finally, security measures involve encrypted communication protocols and secure database access, ensuring the ethical operation and privacy of the collected data.

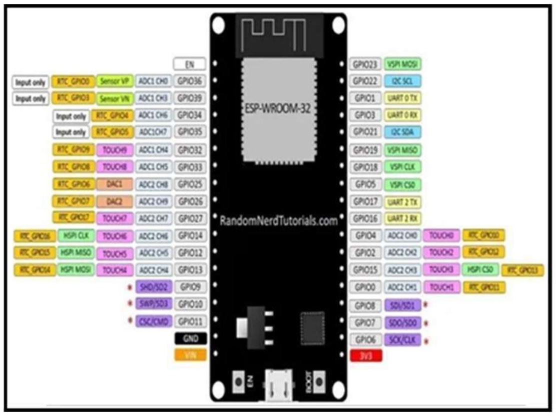

Fig.1. Pin configuration of ESP32 WiFi Module

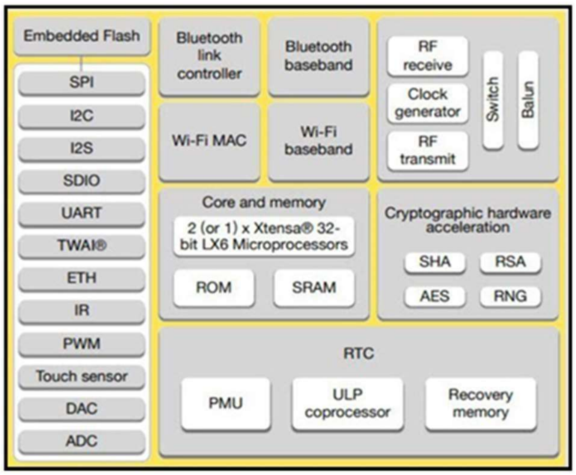

Fig. 2. Block Diagram of ESP32 WiFi Module

V. BLOCK DIAGRAM

Fig (3) shows overview of the Smart Dustbin , showcasing the interconnected components and data flow between them. The ESP32 acts as the central processing unit, receiving data from sensors and controlling the servo motor, while the Blynk app offers a user-friendly interface for remote monitoring and control. Fig. 4 shows the overall block diagram of proposed system.

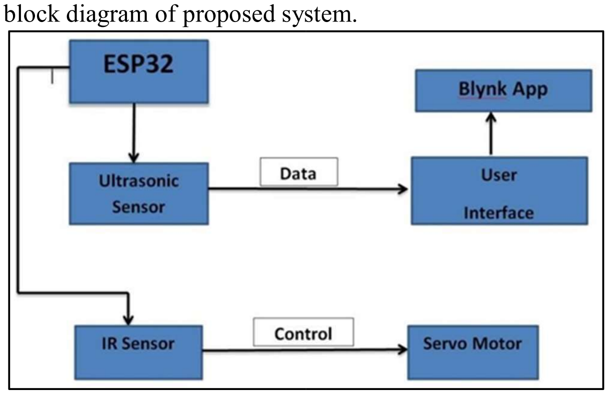

Fig. 3. Smart dustbin block diagram

I. SOFTWARE REQUIREMENT

The software requirements for the IoT and ML-based smart dustbin system are essential to ensure a seamless integration of data processing, machine learning, and user interaction. The system requires a programming environment for development boards such as ESP32 or ESP8266 NodeMCU, where software should be developed to manage data acquisition and communication with IoT sensors. A central server is needed for data processing and preprocessing, potentially utilizing programming languages like Python or Node.js.

For machine learning, software requirements involve frameworks like TensorFlow or scikit-learn to train and deploy the pathfinding model. Additionally, a cloud-based database system, such as AWS DynamoDB or Azure Cosmos DB, is essential for efficient data storage and retrieval. The user interface can be developed using web technologies like HTML, CSS, and JavaScript for ease of access by municipal van drivers.

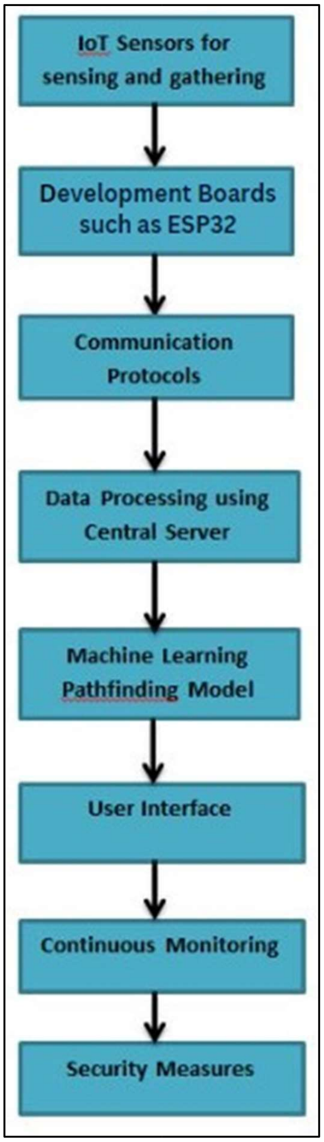

Fig. 4. General block diagram

Security measures necessitate encryption protocols, achievable through libraries like OpenSSL or PyCryptodome. Continuous monitoring and remote maintenance may involve scripting languages like Python. Lastly, for effective communication between components, the MQTT protocol requires software implementation on both the development boards and the central server. Ensuring compatibility and version control across these software components is vital for the successful deployment and operation of the smart dustbin system.

II. Components Requirements

Table 1 enlists the components which are illustrated in the below figures basically taken by considering the sensor requirements of a single dustbin.

TABLE 1 -COMPONENT SPECIFICATION

Component	Specification
Microcontroller	ESP32
Ultrasonic Sensor	HC-SR04 (5V) - SEN-15569
IR sensor	LM 393
Motor	Tower Pro SG90 9G Micro Servo Motor, 5v.

III. Interfacing Diagram

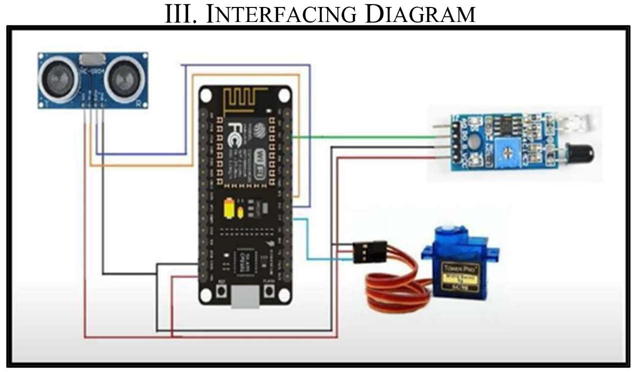

Fig. 5. Interfacing Diagram

Power Supply:

1. Connect the positive terminal of your chosen power source (battery or adapter) to the VIN pin of the ESP32.
2. Connect the negative terminal to the common ground for all components, usually labeled GND.

ESP32 and Sensors:

1. IR Sensor:
   - Connect the VCC pin of the IR sensor to the 5V pin of the ESP32.
   - Connect the GND pin of the IR sensor to the common ground.
   - Connect the OUT pin of the IR sensor to a digital pin on the ESP32.
2. UV Sensor:
   - Connect the VCC pin of the UV sensor to the 5V pin of the ESP32.
   - Connect the GND pin of the UV sensor to the common ground.
   - Connect the OUT pin of the UV sensor to a digital pin on the ESP32 .

ESP32 and Servo Motor:

1. Connect the servo motor's VCC pin to the 5V pin of the ESP32.

2. Connect the servo motor's GND pin to the common ground.
3. Connect the servo motor's Signal pin to a PWM pin on the ESP32 .

IV. Proposed Model

In the proposed technique for the smart dustbin system, the objective is to optimize the travel routes of municipal vans based on real-time fill levels of dustbins using a machine learning model, specifically linear regression. The process begins with the installation of IoT sensors on dustbins, measuring fill levels and tracking locations using GPS modules. This sensor data is then transmitted to a central server, where preprocessing algorithms handle any missing or noisy data and aggregate information over time intervals.

For feature engineering, distances between dustbins are calculated, and fill levels are transformed to enhance the model's understanding. The preprocessed data is stored in a cloud-based database for efficient retrieval. The central server trains a linear regression model using historical data, considering dustbin locations, fill levels, and historical travel paths as features. This model is designed to predict the shortest travel distances between dustbins. In the integration phase, the trained linear regression model is seamlessly incorporated into the system. The user interface, designed for municipal van drivers, allows them to input their current location. The central server, equipped with the linear regression model, dynamically processes this information along with real-time fill levels to provide the shortest path recommendations in real-time. Continuous monitoring ensures that the machine learning model is updated with the latest data, maintaining accuracy. An alert system notifies drivers of urgent dustbin situations. The entire system is secured through encryption protocols to safeguard communication channels and database access. This proposed technique combines IoT data acquisition, cloudbased data processing, and a linear regression model to deliver optimized travel paths for municipal vans. It leverages the simplicity of linear regression for pathfinding while considering real-world factors such as fill levels. The integration of machine learning in the form of linear regression enhances the efficiency of the smart dustbin system, contributing to effective waste management and resource optimization. A simple illustration for how the sensors can be integrated to the dustbin and how the dashboard can look like is illustrated in the figs. (6) (7). The dashboard for simple illustration is been created using the help of Blynk
Iot.

Fig. 6. Hardware setup

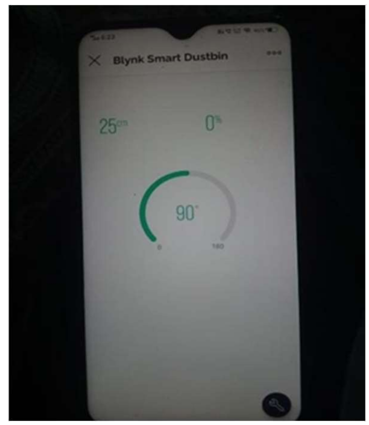

Fig. 7. Blynk App

V. About Datasets

The smart dustbin system heavily relies on a meticulously crafted dataset to effectively train the machine learning model for path optimization. This dataset encompasses a comprehensive array of information related to dustbin locations, fill levels, and historical travel paths, serving as the cornerstone for model development. Each dataset entry likely includes crucial parameters such as latitude and longitude coordinates representing dustbin locations, numerical values indicating fill levels, and historical records of travel distances or times between dustbins.

The dataset's significance lies in its capacity to encapsulate real-world dynamics, enabling the machine learning model to discern intricate relationships among these variables. To ensure robust model training, the dataset ideally incorporates an ample number of samples that portray diverse scenarios encountered in municipal waste management. Moreover, it may encompass temporal aspects, capturing fluctuations in fill levels over distinct time intervals.

To optimize performance, rigorous curation of the dataset is imperative, addressing potential challenges like missing or noisy data. Standard preprocessing steps, such as normalizing numerical features, encoding categorical variables, and handling outliers, become essential. These measures are crucial to guarantee the accuracy and generalizability of the model, as the dataset's quality directly influences the system's ability to deliver precise and dependable predictions. The meticulous construction and refinement of the dataset emerge as a pivotal factor in the seamless and effective implementation of the smart dustbin system.

VI. Results And Discussion

The implemented smart dustbin system, featuring ultrasonic and IR sensors, showcases consistent and precise fill-level measurements, ensuring efficient monitoring of dustbin capacity. The lid control mechanism operates seamlessly, facilitating timely and convenient waste disposal. The ESP32 microcontroller effectively interfaces with sensors, enabling real-time communication and enhancing system responsiveness. Integration with the Blynk app enables users to receive instant updates on the dustbin's status, contributing to a streamlined waste management process. Extensive testing underscores the system's reliability and robustness in responding to changing conditions.

This project not only demonstrates the feasibility of addressing urban waste management challenges but also suggests future developments. Focus areas include feature enhancement, energy optimization, and deeper integration with smart city infrastructure. Ultrasonic sensors improve waste management efficiency by providing real-time data, while IR sensors automate lid control for a hygienic disposal process.

Blynk integration with ESP32 offers a user-friendly remote monitoring platform, fostering proactive waste management. The modular design allows easy scalability, accommodating additional features or sensors based on specific waste management needs. The Blynk app serves not just as a practical tool but also educates users about waste generation habits, promoting responsible disposal practices through its informative features. In summary, the implemented smart dustbin system represents a practical and engaging solution, laying the foundation for future advancements in urban waste management.

Table 1. Accuracy of the model

Condition	Attempts	Accuracy in %
Lip Opening	50	98%
Lid Closing	30	96%

Table 2. Response time

Condition	Time Required
Lid opening	1000 milisec
Lid closing	10 milisec

The proposed technique effectively combines IoT data acquisition, cloud-based data processing, and a linear regression model to provide optimized travel paths for municipal vans in real-time. The system's simplicity, efficiency, and integration of machine learning principles contribute to its potential for practical implementation in waste management scenarios, demonstrating advancements in urban efficiency and sustainability. Further refinements and scalability considerations can be explored to enhance the system's applicability in larger urban environments.

VII. Future Scope

The smart dustbin system, combining IoT and machine learning, holds promising future prospects with potential advancements in waste management, sustainability, and urban efficiency. One significant avenue for future development involves the integration of more advanced machine learning models. While linear regression serves as a baseline, employing more sophisticated algorithms like deep learning or reinforcement learning can enhance the system's ability to adapt to complex and dynamic urban environments. These advanced models can capture intricate patterns in data, improving the accuracy of path predictions and optimizing travel routes further.

Furthermore, the implementation of edge computing can be explored to process data closer to the source, reducing latency and enhancing real-time capabilities. Edge computing devices, strategically placed near dustbins, can preprocess data before transmitting it to the central server, streamlining the communication process and minimizing network congestion. The smart dustbin system can also be extended to incorporate additional environmental sensors. Beyond fill levels, sensors measuring air quality, temperature, or humidity can contribute valuable data for a comprehensive understanding of the urban environment. This expansion enables municipalities to make informed decisions not only about waste collection but also about broader aspects of urban planning and environmental management.

Collaboration with smart city initiatives represents another promising avenue. Integrating the smart dustbin system into a broader ecosystem of interconnected urban technologies can foster synergies, leading to more holistic and efficient smart city solutions. This collaboration may involve sharing data with traffic management systems, optimizing transportation routes beyond waste collection, and contributing to a city-wide network of intelligent infrastructure.

As technology evolves, the smart dustbin system could benefit from the integration of 5G connectivity, enabling faster and more reliable communication between devices. This advancement would further enhance the responsiveness and scalability of the system.

References

[1] J. Gutberlet, "Waste in the City: Challenges and Opportunities for Urban Agglomerations," in Urban Agglomeration, M. Ergen, Ed., InTech, 2018. doi: 10.5772/intechopen.72047.

[2] D. Vij, "Urbanization and Solid Waste Management in India: Present Practices and Future Challenges,"

Procedia - Soc. Behav. Sci., vol. 37, pp. 437–447, 2012, doi: 10.1016/j.sbspro.2012.03.309.

[3] Y. Panchal, B. Sangtani, A. Umargekar, S. Hanumante, and N. Mehendale, "Smart Dustbin: Arduino Controlled Servo Motor and Ultrasonic Sensor," SSRN Electron. J., 2023, doi: 10.2139/ssrn.4513779.

[4] J. Gunaseelan, S. Sundaram, and B. Mariyappan, "A Design and Implementation Using an Innovative DeepLearning Algorithm for Garbage Segregation," Sensors, vol. 23, no. 18, p. 7963, Sep. 2023, doi: 10.3390/s23187963.

[5] A. S. Wijaya, Z. Zainuddin, and M. Niswar, "Design a smart waste bin for smart waste management," in 2017 5th International Conference on Instrumentation, Control, and Automation (ICA), Yogyakarta, Indonesia:

IEEE, Aug. 2017, pp. 62–66. doi: 10.1109/ICA.2017.8068414.

[6] D. Patel, A. Kulkarni, H. U. | S. Sharma, and MET's Institute of Engineering, Nashik, Maharashtra, India, "Smart Dustbins for Smart Cities," Int. J. Trend Sci. Res. Dev., vol. Volume-3, no. Issue-3, pp. 1828–1831, Apr. 2019, doi: 10.31142/ijtsrd22993.

[7] Z. Hisham Che Soh, M. Azeer Al-Hami Husa, S. Afzal Che Abdullah, and M. Affandi Shafie, "Smart Waste Collection Monitoring and Alert System via IoT," in 019 IEEE 9th Symposium on Computer Applications & Industrial Electronics (ISCAIE), Malaysia: IEEE, Apr. 2019, pp. 50–54. doi: 10.1109/ISCAIE.2019.8743746.

[8] G. S. Rohit, M. B. Chandra, S. Saha, and D. Das, "Smart Dual Dustbin Model for Waste Management in Smart Cities," in 2018 3rd International Conference for Convergence in Technology (I2CT), Pune: IEEE, Apr. 2018, pp. 1–5. doi: 10.1109/I2CT.2018.8529600.

[9] S. Sharma*1, "Smart Dustbin Management System," May 2018, doi: 10.5281/ZENODO.1241432.

[10] S. Sreejith, R. Ramya, R. Roja, and A. S. Kumar, "Smart Bin For Waste Management System," in 2019 5th International Conference on Advanced Computing & Communication Systems (ICACCS), Coimbatore, India:

IEEE, Mar. 2019, pp. 1079–1082. doi: 10.1109/ICACCS.2019.8728531.

[11] J. Abedalrahim et al., "DEVELOPMENT OF SMART DUSTBIN BY USING APPS," J. Eng. Appl. Sci., vol. 14, pp. 3703–3711, Nov. 2019.

[12] Teaching Associate, School of ECE. REVA University.Bangalore-India., A. C.S., S. G, UG Scholar,bSchool of ECE. REVA University. BangaloreIndia., S. S, and UG Scholar School of ECE. REVA University. Bangalore-India., "A Smart Dustbin using Mobile Application," Int. J. Innov. Technol. Explor. Eng., vol. 8, no. 11, pp. 3964–3967, Sep. 2019, doi: 10.35940/ijitee.K2129.0981119.

[13] M. Johnson and D. C. E. Shyni, "SMART GARBAGE BIN WITH EFFICIENT ROUTING AND MANAGEMENT SYSTEM," 2019. [Online]. Available: https://api.semanticscholar.org/CorpusID:237953412

[14] S. V. Kumar, T. S. Kumaran, A. K. Kumar, and M. Mathapati, "Smart garbage monitoring and clearance system using internet of things," in 2017 IEEE International Conference on Smart Technologies and Management for Computing, Communication, Controls,

Energy and Materials (ICSTM), Chennai, India: IEEE,

Aug. 2017, pp. 184–189. doi: 10.1109/ICSTM.2017.8089148.

[15] R. K. A. R. Kariapper, P. Pirapuraj, M. S. S. Razeeth, A. C. M. Nafrees, and K. L. M. Rameez, "Smart Garbage Collection Using GPS & Shortest Path Algorithm," in 2019 IEEE Pune Section International Conference (PuneCon), Pune, India: IEEE, Dec. 2019, pp. 1–6. doi: 10.1109/PuneCon46936.2019.9105674.

[16] P. Anitha et al., "Smart Garbage Maintenance System Using Internet of Things," in 2018 3rd International Conference on Communication and Electronics Systems (ICCES), Coimbatore, India: IEEE, Oct. 2018, pp. 1084–1086. doi: 10.1109/CESYS.2018.8724041.

[17] Ji-Xian Xiao and Fang-Ling Lu, "An improvement of the shortest path algorithm based on Dijkstra algorithm," in 2010 The 2nd International Conference on Computer and Automation Engineering (ICCAE), Singapore: IEEE, Feb. 2010, pp. 383–385. doi: 10.1109/ICCAE.2010.5451564.