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Eco Friendly Waste Solution: A Path to Responsible Resource Management

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Abstract

By leveraging data and technology, smart waste management seeks to increase the trash industry's efficiency. Utilizing IoT (Internet of Things) technology, smart garbage management aims to optimize resource allocation, reduce operational expenses, and enhance the sustainability of waste services. The design and implementation of an Internet of Things (IoT)-based waste management system, comprising a humidity sensor for wet/dry waste segregation and a smart bin with a fill level indicator, are included in this study. The system also includes location tracking of the dustbin for efficient waste collection. The fill level indicator provides real-time data to optimize waste collection, while the humidity sensor enables segregation and appropriate disposal of wet and dry waste. The location tracking feature ensures that the waste is collected from the bins promptly, reducing environmental pollution and improving public health.

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1. INTRODUCTION

Managing waste has become a significant challenge for urban areas worldwide, primarily due to the escalating volume of waste generated on a daily basis. Traditional waste collection methods, often based on periodic schedules, result in overflowing bins, poor sanitation, and environmental pollution [1]. To address these issues, there is a pressing need for a smarter approach to waste management that makes use of technology to improve public health, minimize environmental effect, and maximize waste collection. In response to this need, the study proposes an IoT-based waste management system that incorporates real-time data on the fill level and humidity of garbage bins, enabling efficient waste collection and segregation [2].

The proposed system aims to revolutionize waste management with the use of Internet of Things (IoT) technology [4]. By monitoring the fill level and humidity of dustbins in real time [2,5], we can optimize waste collection efforts and minimize overflowing bins. This not only improves the efficiency of waste collection but also contributes to a cleaner and healthier environment [5].

The environmental benefits of implementing such a system are substantial. Recycling plays a vital role in reducing the amount of waste that goes into landfills and positively impacts the environment [4]. By collecting waste and promoting recycling [8], this system can help decrease carbon footprint and foster a sustainable planet.

Additionally, the system offers improved efficiency by utilizing technology to track and monitor the waste collection process [6]. By optimizing collection routes and schedules, the time and resources required for waste collection can be reduced, resulting in cost savings and increased operational efficiency [1].

The convenience factor cannot be overlooked either by strategically placing waste bins with separate compartments for dry and wet waste in public areas [5], individuals find it easier to dispose of their waste correctly. It makes it easier for individuals to dispose of their waste correctly when waste bins with distinct sections for dry and wet waste are placed in public spaces. This may inspire more individuals to take part in recycling and trash minimization initiatives. This convenience encourages greater participation in recycling and waste reduction efforts, thereby promoting a cleaner and greener community [5]. This has the potential to raise standard of living.

Furthermore, the system aims to reduce contamination and enhance the quality of recycled materials [8]. By separating dry and wet waste and effectively managing the waste collection process [8], the risk of contamination is minimized, leading to improved recycling outcomes and the preservation of resources [8].

Rapid urban trash increase combined with a dearth of or ineffective closed-loop waste management methods ensures sustainability. Building waste management infrastructure is essential to attaining sustainable development. India's rapidly increasing population is causing the country's natural resources to be exhausted. Potential resources are wastes, and effective SWM necessitates both resource extraction and effective waste management. Material, energy, and nutrient recovery must be the main objectives of SWM infrastructure development in India in the future. India's urban garbage production is estimated to be 170,000 tons per day, or 62 million tonnes annually. Due to changing lifestyles and population growth, this amount is predicted to rise by 5% year.

Ultimately, the implementation of a garbage management system based on IoT not only benefits the environment but also has a positive impact on the community as a whole [7]. By collecting waste from public areas [7], promoting recycling [8], and maintaining cleanliness can contribute to a higher quality of life and sustainable development [7].

We shall examine the design and implementation in the ensuing parts, and evaluation of the suggested trash management system based on IoT. We will explore the technological components [2], the data analysis techniques employed [6], and the possible advantages and difficulties of implementing it[4]. Through this, we aim to demonstrate the feasibility and effectiveness of our system in revolutionizing waste management practices and creating a cleaner and healthier environment for all.

2. LITERATURE REVIEW

The literature reviews discussed in this analysis provide valuable insights into various aspects of smart waste management.

Review [1] presents alternative operational management approaches regarding the intelligent garbage collection route issue, highlighting the need for optimization in waste collection routes. One of the key advantages is the ability to utilizing real-time data to optimize waste pickup routes and dynamic variables like garbage generation trends and traffic circumstances.

Review [2] focuses on automating solid waste bin condition control with integrated sensing systems and algorithms, emphasizing the importance of automation in waste management. Furthermore, smart waste management systems enable better resource allocation by providing accurate and timely data on waste generation rates.

Review [3] discusses an IoT-driven solid waste management solution for smart cities, emphasizing how IoT may increase the effectiveness of trash management. In addition to operational benefits, smart waste management systems have the potential to enhance citizen engagement and participation in waste management processes.

Review [4] examines how smart systems and the Internet of Things (IoT) can be used in garbage management, talking on the possible advantages and difficulties of doing so. Moreover, the implementation of smart waste management systems aligns with the broader goals of smart city development.

the combined evaluative review [1, 2, 3, 4] highlights the significance of optimization, automation, and real-time monitoring in smart waste management. The alternative operational management approaches, integrated sensing systems, and IoT-based solutions discussed in the literature reviews offer practical recommendations for waste management practitioners and policymakers [1, 2, 3, 4]. While challenges exist, advancements in technology and a collaborative effort from all stakeholders can drive the application of sustainable and effective waste management techniques in smart cities.

Review [5] offers a smart garbage can with the ability to monitor things in real time, emphasizing the importance of real-time data in waste management decision-making. By implementing real-time monitoring and feedback mechanisms, residents can actively contribute to waste management by being informed about waste bin status, receiving notifications on collection schedules, and reporting issues or concerns.

Review [6] presents a case study that offers useful insights into the prospects and problems of smart waste management regarding the integration of smart devices in waste collecting procedures.

Review [7] surveys garbage collection and monitoring systems with an emphasis on IoT technology integration, for smart cities.

Finally, Review [8] discusses sophisticated IoT-based rubbish collection in smart cities, highlighting the potential of IoT in revolutionizing waste management practices. For example, waste collection vehicles can run on sustainable energy sources, or waste-to-energy conversion facilities can be integrated with the power grid to generate electricity from organic waste, contributing to a more sustainable energy mix [7, 8].

In conclusion, smart waste management systems offer numerous benefits that go be5 yond operational improvements. They optimize waste collection routes, improve resource allocation, enhance citizen engagement, and align with the broader objectives of smart city development [3, 4, 7, 8]. These systems help create a more sustainable and livable urban environment by utilizing technology and data-driven methodologies, promoting resource efficiency, reducing environmental impact, and fostering community participation in waste management processes [1, 2, 5].

the exploratory review of the literature emphasizes the significance of IoT garbage bins equipped with fill level indicators, weight sensors, and humidity sensors in optimizing waste management processes. Real-time monitoring, data-driven decision-making, and route optimization based on actual fill levels are made possible by these technologies. While challenges related to data management, infrastructure, and user acceptance exist, the benefits of implementing IoT garbage bins include cost reduction, improved efficiency, and better resource allocation. By leveraging these technologies, waste management authorities can enhance their operations and contribute to a more sustainable and effective waste management system.

The instrumental implications and recommendations from the literature reviews align closely with the project of implementing IoT garbage bins using fill level indicators, weight sensors, and humidity sensors, while also optimizing routes. By adopting alternative operational management approaches, utilizing integrated sensing systems, and leveraging IoT-based solutions, waste management practitioners can optimize waste collection routes, automate bin state management, and make data-driven decisions. Addressing challenges related to data management, infrastructure, and user acceptance will be essential for the successful implementation of the project and realizing the benefits of smart waste management systems.

3. PROPOSED WORK

1. IoT-Based Waste Monitoring Systems:

Sensor Technologies:

Numerous studies have utilized various sensor technologies for waste monitoring, including weight sensors, fill level indicators using sonar sensors, and humidity sensors. Weight sensors allow real-time monitoring of the garbage bin's weight, providing valuable insights into the fill level and enabling proactive waste collection. Fill level indicators, leveraging sonar sensors, accurately measure the waste fill level within bins, ensuring timely collection and efficient resource allocation. Additionally, humidity sensors contribute to environmental monitoring, detecting potential odors or hazardous conditions.

Connectivity and Data Transmission: Reliable connectivity and smooth data transfer are essential for the successful integration of IoT technology into waste management systems. Sensor data can be transferred to a central server or cloud platform via wireless communication protocols like Wi-Fi, Bluetooth, or LoRaWAN. Decision-making, data analysis, and real-time monitoring are made easier by this interconnectedness.

2. Waste Collection and Routing Optimization:

Route Optimization Algorithms: Efficient waste collection involves the optimization of collection routes based on real-time data from IoT-enabled garbage bins. Route optimization algorithms, aim to minimize travel distances and time, reduce fuel consumption, and enhance overall operational efficiency. These algorithms consider various factors, including the fill level of bins, traffic conditions, and geographical information, to generate optimized routes for waste collection vehicles.

Location-Based Services: The incorporation of location-based services in waste management systems allows for precise tracking and monitoring of garbage bins' locations. Global Positioning System (GPS) enables real-time tracking, ensuring accurate positioning and facilitating route optimization based on bin locations. This information is vital for waste collection fleet management, enabling efficient allocation of resources and timely response to dynamic waste generation patterns.

3. **Waste Sorting and Recycling:**

Warehouse Operations: Once waste is collected, it is transported to a centralized warehouse for further processing and sorting. Advanced waste sorting techniques, such as automated sorting machines using machine vision and AI algorithms, increase the trash segregation process' accuracy and efficiency. Real-time monitoring of warehouse operations, including waste storage capacity and inventory management, ensures streamlined processes and optimal resource allocation.

Recycler Integration: Recyclers must be integrated into the waste management system in order to support recycling programs. Recyclers can access a digital platform or application to place orders for specific quantities of recyclable waste. This integration enhances the circular economy by establishing transparent communication channels between waste collectors and recyclers, facilitating the recycling process and reducing waste sent to landfills.

4. FRAMEWORK AND SYSTEM DESIGN

In Fig. 1 The dustbins can send real-time data about the amount of rubbish they contain since they are connected to a cloud-based network. This information is then transmitted to aggregators, which are also connected to the same cloud-based platform.

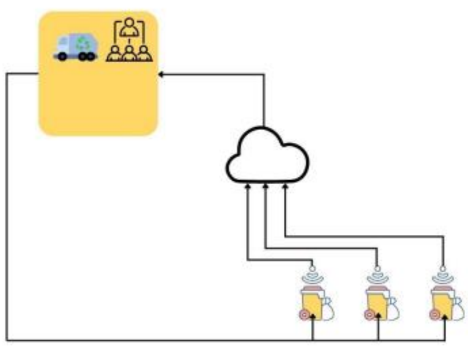

Fig. 1 Overview of the system

The role of the aggregators is to collect data from multiple sources, such as different dustbins, and aggregate it in a meaningful way. Finally, the waste collectors are connected to the same cloud-based platform via the aggregators. This enables them to more effectively organize their collection routes and get information on the condition of various waste bins. Overall, this connected system provides a more efficient and effective waste management solution.

4.1 Framework

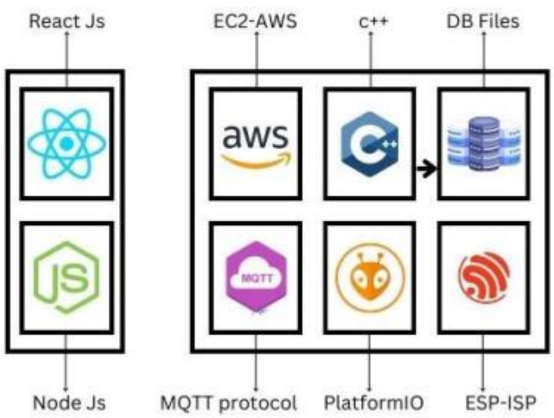

Fig. 2 Framework of the system

The proposed system architecture(Fig 2) for the IoT-based waste management solution incorporates various technologies and frameworks to create a comprehensive and efficient system. The key technologies utilized in this architecture include:

- Front-end Development: ReactJS, a widely adopted JavaScript library, is employed for building the user interface, following a component-based development approach.
- Server-side Application: Node.js, known for its non-blocking I/O model, is utilized to develop the server-side application responsible for handling incoming requests from the front-end.
- Cloud Platform: AWS IoT is chosen as the cloud platform for secure transmission of data from the dustbins to the server. It offers managed services suitable for handling large volumes of data from IoT devices, including features like device shadows for offline interaction.
- Database Interaction: C++ programming language is employed for efficient data retrieval from the database containing dustbin information due to its high-performance and low-level memory manipulation capabilities.
- Messaging Protocol: MQTT, a lightweight messaging protocol, is used for seamless communication between the dustbins and the server. It ensures efficient network bandwidth utilization and low CPU usage.
- Integrated Development Environment (IDE): PlatformIO, a versatile cross-platform IDE tool, is utilized for programming embedded systems and software. It facilitates development across different hardware platforms and expedites the development process.
- Firmware Programming: ESP-ISP, an in-circuit programming tool, is utilized for uploading firmware to ESP32 microcontrollers. ESP32, known for its IoT capabilities, low power consumption, and connectivity features, is extensively used in the system.

The proposed system architecture exemplifies a typical IoT application stack, where devices communicate with a cloud platform that provides storage, analytics, and management services. The combination of ReactJS, Node.js, AWS IoT, C++, MQTT, PlatformIO, and ESP-ISP showcases the diverse range of technologies and frameworks employed in building a comprehensive IoT solution for waste management.

4.2 Workflow

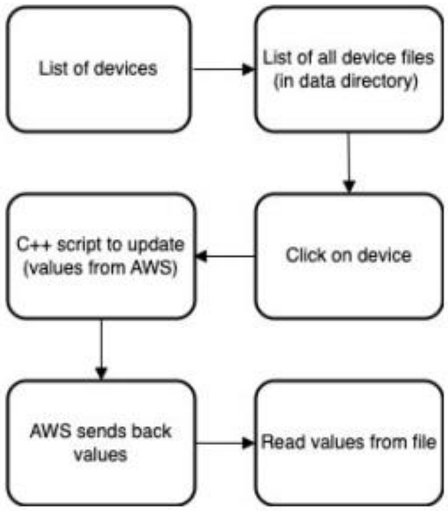

Fig. 3 Workflow of the system

The system's workflow is displayed in Fig. 3. The frontend component of the system presents a user-friendly interface displaying a list of devices (dustbins). This list is obtained from a database or API and includes device names or IDs for identification purposes.

When a user selects a device from the list, the frontend initiates a C++ script responsible for updating the device's information. The script utilizes an AWS SDK to establish a connection with AWS and retrieve the latest data associated with the selected device. This data encompasses details such as the dustbin's current fill level, the timestamp of the last emptying, and any relevant error messages.

Upon receiving the updated values from AWS, the C++ script processes the data and updates the corresponding device file located in the data directory. Subsequently, the frontend retrieves the updated values from the file and presents them to the user. The displayed information may include the revised fill level percentage, the updated last emptying time, and any generated error messages.

This workflow ensures that the frontend consistently provides real-time, up-to-date information regarding the devices (dustbins). By establishing a connection to AWS and updating the device files, the system guarantees that users are continuously informed about the status of each device.

4.3 Activity Diagram

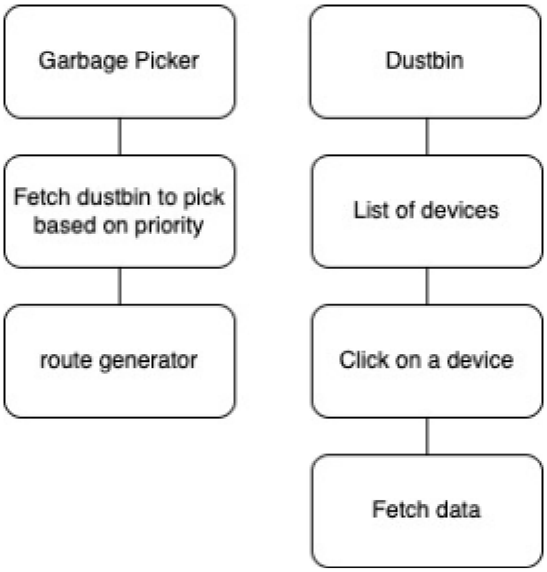

Fig. 4 Activity Diagram of the system

In garbage collection process, the frontend allows the garbage picker to select a dustbin by clicking on it from the device list. Subsequently, the frontend searches for the corresponding device file in the data directory, which stores essential information about the device's status and recent updates.

Relevant data, such as the dustbin's current fill level and location, is retrieved from the device file. This information serves as the basis for prioritizing the dustbins based on fill level or proximity to the garbage picker's current location.

Using an algorithm, a route is generated for the garbage picker based on the selected dustbin and other prioritized dustbins. The route calculation takes into account factors such as distance, traffic conditions, and road conditions.

The generated location and route information are displayed to the garbage picker in the frontend. This visualization can include a map or other graphical tools to present the route and the locations of the dustbins.

To streamline the process, the garbage picker is provided with the capability to mark the selected dustbin as picked once the garbage has been collected. This update is reflected by modifying the device file in the data directory and updating the device list in the frontend accordingly.

This workflow enables efficient garbage collection by leveraging data from the device files, generating optimized routes, and giving the garbage picker real-time location information.

5. CONCLUSIONS

The proposed IoT-based waste management system demonstrates the potential to address the challenges faced by cities and communities in efficiently managing waste. By leveraging IoT technology, cloud connectivity, and data analytics, the system offers real-time monitoring of dustbin fill levels and location, optimizing garbage collection routes and promoting effective waste management practices.

Through the implementation of this system, several key findings emerge. Firstly, the calibration of dustbin sensors ensures accurate fill level measurements, providing precise data for analysis. Secondly, the real-time data collection from IoT sensors enables insights into waste generation patterns, facilitating informed decision-making. Thirdly, the implementation and testing of a route optimization algorithm based on collected data results in efficient collection routes, minimizing travel distance and enhancing overall waste management efficiency.

The experimental results validate the effectiveness of the proposed system. Dustbin sensor calibration, real-time data collection, and route optimization algorithm implementation demonstrate successful integration and functionality. The accuracy and reliability of the dustbin sensors are confirmed through comparisons with physical inspections.

This study adds to the corpus of knowledge already in existence by showcasing the application of IoT technology in waste management. The adoption of technologies such as ReactJS for the frontend, Node.js for the server-side application, AWS IoT for cloud connectivity, C++ for data retrieval, MQTT for messaging, and PlatformIO for embedded systems programming exemplifies the diverse range of tools and frameworks required to develop a comprehensive IoT solution.

By providing up-to-date information on dustbin fill levels and optimizing garbage collection routes, the proposed system offers significant potential for improving waste management practices. The integration of IoT technology, cloud connectivity, and data analytics allows for improved resource allocation, lower operating expenses, and favourable effects on society and the environment. Moreover, further exploration of data analytics techniques and optimization algorithms can enhance the system's efficiency and scalability.

In summary, the IoT-based trash management system that has been shown shows encouraging results and advances the use of sustainable waste management techniques.

Conflicts of Interest:

The writers have disclosed no conflicts of interest. The manuscript's contents have been reviewed by all co-authors, who concur with its contents and have no financial interests to disclose. We attest that the submission is unique and hasn't been published anywhere else.

Author Contributions:

Mushtaq Ahmed conceived and designed the study. Nandini S B collected the data. Brunda L analyzed the data and interpreted the results. Dr. Naseer R contributed to the statistical analysis. Sangeetha Rao S wrote the manuscript, and each author made important changes. The final draft of the manuscript was approved for submission by all authors.

Future Scope: The implementation of a recycler's dustbin can be further enhanced by integrating it with smart city infrastructure.

The recycler's dustbin can also be further improved by adding more sensors and features, such as an odor sensor, a camera for detecting inappropriate waste disposal, or even a machine learning algorithm for predicting future waste production and patterns of cyclical waste disposal. A smart dustbin can be equipped with an RFID or barcode scanner to identify the type of waste being disposed of. Adding an air quality sensor to a smart dustbin can help in detecting harmful gases emitted from the waste, providing real-time data on the level of pollution in the surrounding environment.

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