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Smart Waste Management Using IOT And Edge Computing

Abstract:

In several locations, municipal waste bins are overflowing and are not cleaned in a timely manner. The repercussions are severe as a result. It encompasses the overflow of waste, leading to land contamination and the proliferation of illnesses. It also engenders unsanitary circumstances for individuals and detracts from the aesthetic appeal of the area. A system should be established to monitor the bin and provide information on its filling to the municipality via a wireless sensor network, ensuring timely cleaning and environmental protection. The intelligent waste management system that detects bin capacity with a wireless sensor network (WSN). The technology offers a web interface for the cleaning authority to oversee and maintain the rubbish bin. Ultra-sonic sensors are used to ascertain the condition of the dust bins. The Node-MCU reads the status and transmits it to the cloud server (THING SPEAK). The server managed at the municipality of office will analyze this data to ascertain which dustbin need emptying or is full, and will promptly notify the driver to collect the rubbish.

Keywords: Municipal garbage bin, Ultrasonic sensor, Node MCU, Thing SPEAK, Monitoring.

Introduction

After reaching 7.8 billion in 2020, the current population of the globe is anticipated to reach 9.9 billion by the year 2050, according to one estimate1. This represents an increase of more than 25 percent from the existing population. Because of the progressive migration of a significant number of people to urban areas and the expansion of the world's population, the notion of smart cities is becoming an increasingly important topic of discussion. A smart city is a concept that involves integrating a variety of information and communication technologies, such as the Internet of Things (IoT), in order to manage public space and municipal services in a way that is environmentally friendly.

The effects of climate change and the events that follow, such as increasing sea levels, flooding caused by shifting river flows, and an increased likelihood of greenhouse heat islands [1], are significant obstacles to the achievement of sustainable development. In addition, in line with [1], it is necessary to identify the elements that generate significant limits for cities. These variables include demographic shifts, as well as technical, economic, social, and environmental issues. When it comes to the field of sustainable development, one of the most essential routes to take is the design and implementation of monitoring and management systems for trash collection and disposal. Increasing urbanization, affluence, and consumption all contribute to a rise in the amount of garbage that is produced. The quantity of garbage that is estimated to be produced around the globe is projected to reach 2.2 billion tons by the year 2025, as shown by several estimations [2, 3].

The efficient organization of waste collection and processing is a necessary service and a challenging task for any

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large organization. This includes the analysis of data from sensors on smart garbage bins (SGBs), garbage trucks, and urban infrastructure; the planning and optimization of routes; the provision of information and decision support for users (drivers, dispatchers, and citizens); the classification and segregation of waste; the provision of payments and benefits to citizens; and the monitoring of the ecological situation. Currently, such a system will most likely be based on Internet of Things technology, form a SWM system consisting of a large number (potentially billions) of smart devices that communicate with standard protocols, have physical and virtual characteristics, are intelligent (based on artificial intelligence), and are able to measure, calculate, transmit, store, and process information. Other characteristics include the ability to communicate with standard protocols. The implementation of solid waste management (SWM) systems, which include the usage of information and communication technology (ICT) in waste management, would result in an increase in the energy efficiency and environmental safety of solid waste exports, as well as an improvement in the quality of life of people and a reduction in the consumption of resources [5].

the city. It is for this reason that smart waste management (SWM) may be considered a crucial component of a smart city, and it necessitates a strategy that is both complicated and multi-criteria [4]. For SWM, collection is required.

Literature Review

Researchers have presented several overviews of solid waste management methods and technologies. Numerous research concentrate on urban-level solid waste management systems, services, methodologies, and technology. For instance, [4] offers a systematic review and study of city-level services inside SWM systems, including aspects such as architecture, decision support systems (DSS), geographic information systems (GIS), dynamic scheduling, dynamic routing, social context, and experimental data. In the analysis of the systems discussed in the article, the following attributes are considered: physical infrastructure (type and location of SGB, pneumatic pipes, truck fleets, depots, dumps, recycling, and processing) and software analytics (architecture, decision support systems (DSS), geographic information systems (GIS), dynamic scheduling, dynamic routing, and social context). This review focuses on the energy efficiency of IoT. It seeks to showcase a diverse array of models pertinent to efficient waste management. Particular emphasis is placed on waste removal. The authors see the need of establishing an efficient trash collection model using IoT, which will include large-capacity garbage trucks as mobile warehouses, and will also design a model to optimize the placement of rubbish bins for the utmost convenience of inhabitants.

Reviews systems engineering methodologies in the creation of integrated solid-waste management for a smart city. Three systems engineering methodologies—specifically GIS, multi-criteria decision-making, and life-cycle analysis—were evaluated in relation to solid-waste management systems. The authors found that systems must have a holistic, comprehensive, and multidisciplinary framework that integrates technological, economic, and social elements, stakeholders, and timeframes. The use of ICT in solid waste management enhances communication among various system components and provides data for decision-making and administrative functions. The authors in [7] provide a comprehensive assessment of ICTs and operations research methodologies used in solid waste management (SWM), detailing the processes for which these were implemented and identifying the nations exploring solutions for solid waste management over the 2010-2013 timeframe. Devi presents an analysis of solid-waste management models in [8]. Nine waste management models are examined to determine which existing model could be exclusively implemented in Indonesia's transitioning villages. The analysis highlights that the solid waste management model must prioritize (1) local community participation, (2) waste transport patterns and management types that do not impose significant financial burdens, and (3) management infrastructure that can be established and sustained by community or local organizations. The authors in [7] provide a comprehensive evaluation of information and communication technologies (ICTs) and operations research methodologies used in solid waste management (SWM), detailing the processes involved and identifying the nations exploring solutions for solid waste management over the 2010-2013 timeframe. The survey indicated that China distinguished itself among nations with the most diversified offers, whilst Malaysia contributed mostly to ICT integration and heuristics.

Among the operational methodologies, GIS was predominantly used, often in conjunction with other technologies. The predominant operations research techniques from 2010 to 2013 were mathematical optimization, multi-criteria decision analysis, and heuristic approaches. The writers emphasize the significance of the social dimension, including studies on people' environmental consciousness and the evaluation of strategies for waste management among the populace.

The authors emphasize the need for more study on the use of operational technologies and ICT in recycling and reverse logistics, along with studies to bolster environmental legislation. The authors also highlight the absence of historical data about waste collection management.

This may result in flawed decision-making and imprecise planning and forecasting. The authors contend that business intelligence tools and methods, including data mining and multivariate analysis, may convert raw data into significant and valuable information, thus offering a novel approach to understanding ICT for decision-making in waste management.

Devi presents an analysis of solid-waste management models in [8]. Nine waste management models are examined to determine which current model might be specifically implemented to Indonesia's transitional villages, using the principles of sustainable urban design by analyzing ten existing models. The study concludes that the solid-waste management model must prioritize (1) local community involvement, (2) efficient waste transport methods and cost-effective waste management practices, and (3) the establishment and maintenance of management infrastructure by community or local organizations.

A separate series of research examines SGB-level services, methodologies, and technologies, including numerous sensors, actuators, and other IoT and communication technologies.

Soni and Kandasamy examine the classifications of SGBs in [9] by classifying systems according to technology (sensors and data transmission), microcontroller, cloud technologies, GPS, and web technologies (web interface of SGB). The analysis encompasses 18 distinct smart bin systems; however, it regrettably only conveys the presence or absence of certain sensors and technology. The research concludes with the authors proposing a framework that addresses the identified demands and deficiencies of current solutions in this domain. Reference [10] offers a comprehensive but unstructured evaluation of IoT-enabled waste technologies and methods in the domains of 1) trash characterisation, 2) waste quantification, and 3) waste management. The deficiencies of current waste management procedures are emphasized, and a conceptual framework for a centralized waste management system is suggested. Reference [4] offers a systematic review and comprehensive study of SWM systems associated with SGB-related services in IoT-enabled smart cities. It examines the integration of diverse sensors in SWM systems (capacity, weight, temperature, humidity, chemical, pressure), actuators, cameras, RFIDs, WSNs, and GPS. Reference [11] delineates and examines several systems for smart waste monitoring, segregation, and collection. The evaluation of 28 solid waste management systems is predicated on the used technology and sensors. In [12], Topaloglu et al. conduct a comparative analysis of Wi-Fi, Cellular, Li-Fi, and drone-based systems for SWM applications. This work aimed to provide type-2 fuzzy multiple criterion approaches for the evaluation and ranking of different garbage collection systems in a smart city context. The research indicated that the drone and visible light communication-based collecting technologies are the most suitable for the study region. These technologies may be favored and implemented within the smart city framework, especially for solid waste collection, and the rankings shown considerable stability despite variations in weighting. The approach presented in this research is applicable to solid waste collection issues in many cities and areas. Chaudhari presents a summary of an IoT-driven rubbish collection management system for smart cities in [13].

A delineation of the operational, fundamental attributes and benefits of the systems in question is presented. The examination concludes with the authors proposing their own solid waste management system. The evaluation lacks any grievances or deficiencies; it does not have a pivot table or any method for comparative analysis of systems. A key finding of the research is the persistent lack of discourse on the potential use of genetic algorithms as an optimization technique for garbage collecting. The authors of [11] delineate and examine several intelligent waste monitoring, segregation, and collecting technologies. The evaluation of 28 solid waste management systems is predicated on the technology and sensors used. The paper presents a schematic design of a smart waste management system using cloud technology, along with a generalized description of the trash segregation scenario employing embedded and GSM technologies. via the examination of ten existing models. The inference derived from the Concept of the Internet of Things

Kevin Ashton first suggested the notion of the Internet of Things (IoT) in 1999, describing it as individually identifiable linked items using radio-frequency identification (RFID) technology. The precise definition of IoT is under development and is contingent upon different views. The Internet of Things (IoT) is defined as a "dynamic global network infrastructure with self-configuring capabilities based on standards and communication protocols."

- In the Internet of Things, both physical and virtual entities own distinct identities and traits, enabling them to use intelligent interfaces and integrate into an information network. The Internet of Things (IoT) may be defined as a collection of interconnected devices that has unique identifiers.
- The terms "Internet" and "Things" refer to a globally interconnected network reliant on sensors, communication, networking, and information processing technologies, potentially representing an advanced iteration of information and communications technology (ICT). Currently, several technologies are integrated into the Internet of Things (IoT), including wireless sensor networks (WSNs), barcodes, intelligent sensing, RFID, NFC, low-energy wireless communications, and cloud computing. The Internet of Things (IoT) refers to the forthcoming evolution of the Internet, whereby actual objects may be accessed and identified via the Internet. The definition of the IoT changes based on the technology used for its execution. However, the essence of IoT indicates that items inside an IoT may be individually identified in their virtual representations. In an IoT, all entities may communicate data and, if necessary, process data according to predefined protocols.

Architecture Of IOT

The Internet of Things (IoT) necessitates that all of the devices that are participating in the network must be linked to one another.

As a means of bridging the gap between the real and virtual worlds, the Internet of Things (IoT) system design must ensure that the IoT can function properly. Designing an architecture for the Internet of Things requires a lot of different things, such networking, communication, procedures, and so on. When developing the architecture of the Internet of Things (IoT), it is important to take into mind the extensibility, scalability, and operability of the distributed devices. The architecture of the Internet of objects need to be flexible in order to enable devices to engage with one another in a dynamic manner and to facilitate communication between them. This is because objects may move and there is a requirement for them to communicate with one another in real time. Additionally, the Internet of Things need to have a decentralized and diverse form of operation.

Service Oriented Architecture

The interconnection of the many devices that make up a network is an essential necessity for an Internet of Things (IoT). It is essential that the design of the Internet of Things (IoT) system ensures the smooth functioning of the IoT, which serves to bridge the gap between the real and virtual worlds. The architecture of the Internet of Things (IoT) is designed with a number of considerations in mind, including networking, communication, business models and procedures, and security. When building the architecture of the Internet of Things (IoT), it is important to take into mind the extensibility, scalability, and interoperability among heterogeneous devices and the models they use. As a result of the fact that objects may move about physically and need to communicate with one another in real time, the architecture of the Internet of objects need to be flexible in order to enable devices to interact with one another in a dynamic manner and to facilitate the exchange of events in a clear and unambiguous manner.

Methodology & Block Diagram

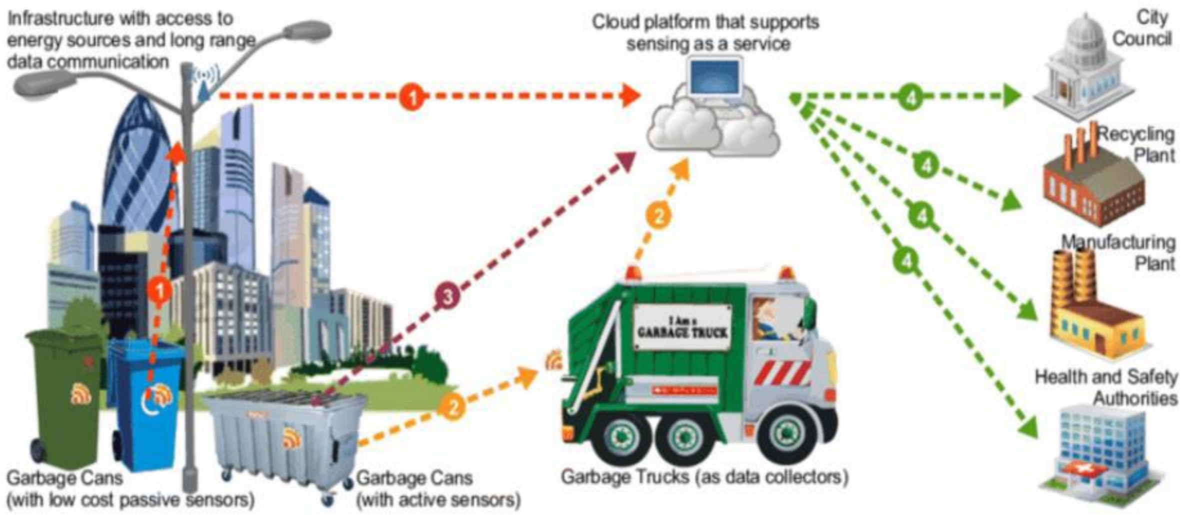

Figure 1: Intelligent waste management System

The intelligent waste management system shown in the top graphic incorporates many technologies, including sensor-equipped rubbish bins, data-gathering refuse vehicles, and a cloud platform that facilitates sensing as a service. This cohesive strategy facilitates real-time surveillance, enhanced collection pathways, and cooperation among many stakeholders, including municipal authorities and recycling centers.

Modern waste management techniques for urban environmental sustainability prioritize systemic transformations, using novel technology and interdisciplinary partnerships. These methodologies amalgamate data-driven decision-making with community-based activities to surmount conventional obstacles to efficient trash disposal and recycling (Jacobi & Besen, 2011). Thus, promoting sustainable urban infrastructure is not just an environmental need but also a means to attain socioeconomic parity and environmental justice.

- The Function of IoT in Intelligent Waste Management

The Internet of Things (IoT) has emerged as a revolutionary technology in urban trash management, providing creative remedies to longstanding inefficiencies. IoT technologies include networked devices that interact across networks to gather, analyze, and transfer data in real time. These systems use sensors, cloud platforms, and sophisticated algorithms to assess garbage levels, enhance collection routes, and forecast maintenance requirements. Anagnostopoulos et al. (2017) highlight the significance of IoT as a fundamental component of smart city frameworks, stressing its contribution to fostering sustainable waste management via data-informed decision-making.

The efficiency improvements offered by IoT in garbage management are diverse. Sensors integrated inside smart bins assess fill levels and relay this data to rubbish collection services, enabling dynamic route optimization and minimizing fuel use. Likewise, real-time data analytics assist in tackling issues such as overflow and inconsistent waste creation patterns, as shown by Nižetić et al. (2020). Furthermore, IoT enhances openness and accountability in trash management by providing stakeholders with precise, real-time information, therefore cultivating public confidence in urban sustainability efforts.

Despite the significant potential advantages, obstacles like connection issues, financial constraints, and the need for defined protocols remain. Nonetheless, via ongoing innovation and policy endorsement, IoT has the potential to markedly improve waste management efficiency, mitigate environmental effects, and synchronize urban infrastructure with overarching sustainability objectives (Scott et al., 2024). As urban environments progressively incorporate IoT technology, the potential for study and application in this field continues to grow (Aborode et al., 2024).

Block diagram

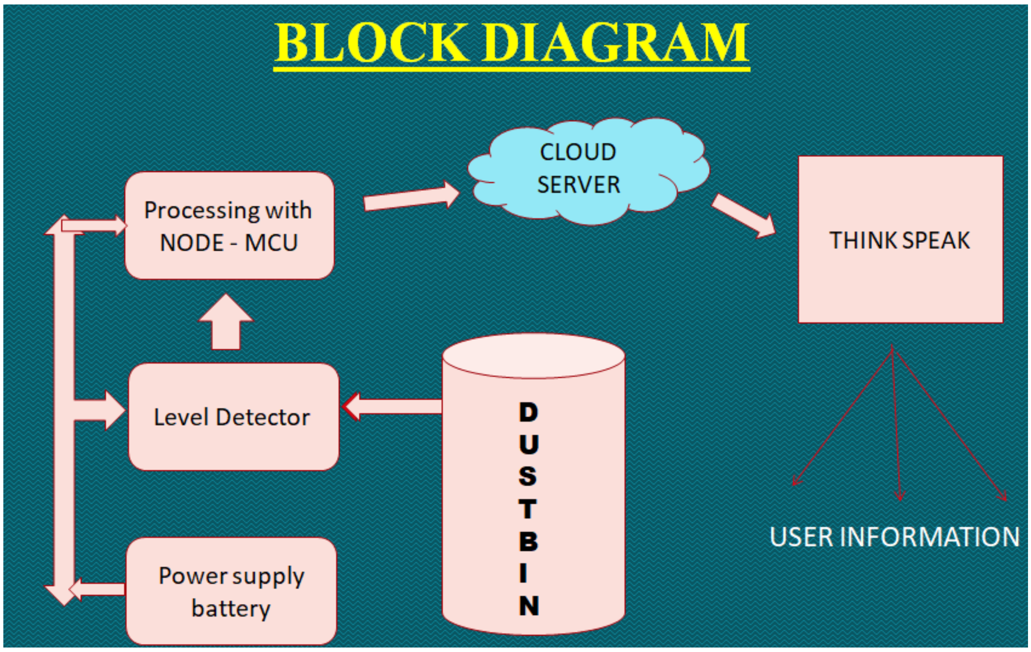

Figure 2: Block diagram

Figure 3:Smart Waste Management

Systems And IOT Technologies

Overview of Smart Waste Management

Smart waste management denotes the use of sophisticated technology and new systems to enhance the processes of waste collection, segregation, transportation, and disposal (Aborode et al., 2024). These systems depend on Internet of Things (IoT) devices, data analytics, and automation to provide efficient, sustainable, and economical solutions. The main aim is to optimize resource recovery, decrease landfill use, and elevate urban cleanliness while reducing environmental and economic expenditures (Cheema et al., 2022).

Essential elements of intelligent waste management systems are sensor-integrated garbage receptacles, real-time surveillance platforms, and automated sorting technologies. Sensor devices, embedded in garbage bins, assess fill levels and transmit data to centralized systems to enhance waste collection routes. Moreover, IoT-enabled solutions collect and analyze data to facilitate predictive maintenance, hence diminishing operational inefficiencies (Esmaeilian et al., 2018). Advanced sorting technologies, including robots and artificial intelligence, enhance the precision of material recovery, so supporting a circular economy model.

Figure 3 delineates the intricate components of a smart waste management system, including ultrasonic sensors, load sensors, microcontrollers, and a central cloud server. This cloud-based architecture allows for the collecting and analysis of data from numerous sensors, hence enhancing the efficiency of garbage collection and management activities.

These systems are underpinned by digital platforms that enable data exchange among stakeholders, such as waste management firms, local authorities, and the public. The amalgamation of cloud computing with blockchain improves transparency and accountability, enabling the efficient monitoring of waste processes from inception to ultimate disposal (Sadov et al., 2022). This holistic strategy not only tackles the urgent issues of trash management but also corresponds with long-term sustainability objectives, establishing it as a fundamental element for smart city projects (Aborode et al., 2024).

IoT Technologies in Waste Management

Smart waste management denotes the use of sophisticated technology and innovative systems to enhance the processes of waste collection, segregation, transportation, and disposal. These systems depend on Internet of Things (IoT) devices, data analytics, and automation to provide efficient, sustainable, and economical solutions. The main goal is to optimize resource recovery, decrease landfill use, and elevate urban sanitation while mitigating environmental and economic expenses (Cheema et al., 2022).

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Emerging Trends and Innovations

Emerging technologies, especially artificial intelligence (AI) and blockchain, are transforming waste management processes by providing creative solutions for data integration, transparency, and efficiency. Algorithms driven by artificial intelligence provide real-time surveillance, prediction analysis, and enhancement of waste management systems. Machine learning models can forecast trash production trends, enabling prompt interventions and enhanced resource allocation (Hait & Hait, 2022). Simultaneously, blockchain technology guarantees safe and transparent data exchanges among stakeholders, tackling challenges such as waste tracking and accountability (Jiang et al., 2023).

The use of AI and blockchain in trash management promotes a circular economy by diminishing waste, improving recycling processes, and lessening environmental effect. Blockchain may be used to authenticate the lifetime of recyclable materials, guaranteeing compliance with sustainability criteria (Tanveer et al., 2022). Moreover, AI enhances the recognition of waste categories and their suitable recycling routes, hence significantly increasing the efficiency of sorting and processing facilities (Baralla et al., 2023). Collectively, these technologies enhance operational efficiency and foster long-term sustainability by diminishing greenhouse gas emissions and preserving resources (Idoko et al., 2024).

Fig 4 Integrating AI and IoT for Sustainable Waste Management within the Digital Circular Economy (Alqudah, 2024)

Figure 4 depicts the circular economy model, whereby trash is seen as a useful resource for recycling and reuse. The core recycling emblem is around by many recycled materials and vehicles, emphasizing a comprehensive approach to trash management within a sustainable urban context.

The enduring effects of these technologies beyond mere operational enhancements. They provide the groundwork for intelligent cities, where integrated systems improve urban sustainability and resilience. Nonetheless, the effective integration of these technologies requires significant investment and regulatory backing to address difficulties like interoperability and data protection. With the rise in usage, other innovations, like the integration of blockchain with Internet of Things (IoT) networks, are expected to transform waste management techniques worldwide.

Conclusion

IoT technology have profoundly impacted the development of intelligent waste management systems and urban planning methodologies. These technologies provide real-time surveillance of trash levels, optimize routing, and augment decision-making processes, hence diminishing operational expenses and environmental repercussions. The capacity to gather and assess substantial quantities of data enables towns to develop effective waste management systems.

These methods not only rectify operational inefficiencies but also conform to the objectives of sustainable urban development. Moreover, the incorporation of IoT in urban planning improves communication across many city sectors, including transportation and waste management. IoT-based technologies facilitate adaptive urban planning by delivering data-driven insights about resource allocation and infrastructure requirements. These systems enable the coordination of various urban services, facilitating the full integration of IoT technology into smart city projects. The potential of IoT in enhancing public engagement is considerable, since real-time data may engage residents and stakeholders in urban planning.

Notwithstanding these benefits, obstacles like data privacy, security issues, and the need for regulatory frameworks persist as significant worries. Confronting these difficulties necessitates cooperative endeavors among technology developers, urban planners, and legislators. Utilizing IoT's potential, cities may advance towards a more sustainable and adaptive urban infrastructure, guaranteeing efficient resource management and the welfare of urban people.

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