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Study on several types of smart bins, functionality, and networking systems for waste collection and management: a review

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Smart waste management systems, using Internet of Things (IoT) technology, sensors, and data analytics, are becoming pivotal in the pursuit of sustainable waste disposal methods. Traditional waste collection and disposal methods have shown limitations and are unsustainable in the context of growing urban populations and rapid urbanization. To address these challenges, IoT and sensor technologies are being used to develop new waste management systems. This paper explores the essential components and benefits of smart waste management systems, which use technology to produce actionable data, increase recycling rates, and improve eco-urban spaces. The integration of smart waste management systems involves installing ultrasonic sensors and RFID tags in waste bins to track waste levels and manage collection routes. This data-driven approach can reduce operational costs, decrease greenhouse gas emissions, and enhance service quality. Additionally, these systems can incorporate citizen engagement platforms, encouraging responsible waste disposal and raising environmental awareness through mobile applications and gamification.

By employing cutting-edge technologies such as machine learning algorithms for route optimization and robotic sorting systems, smart waste management systems enable more efficient, cost-effective, and environmentally friendly methods for managing solid waste, supporting the development of intelligent cities.

Keywords: Waste classification, internet of things (IoT), renewable energy, GSM/GPRS, wireless sensor networks, smart waste management system (SWMS)

INTRODUCTION

In the current metropolitan era, as cities continue to grow and house increasing populations, proper waste disposal is crucial. Traditional waste collection and disposal methods are becoming unsustainable as waste volumes rise. Therefore, innovative and easily implementable solutions are needed to recycle accumulated waste effectively.

Currently, waste collection and disposal rely heavily on manual labor and rigid schedules, which are inefficient in mitigating air pollution and contribute to ongoing environmental challenges. Integrating smart trash cans into waste management garbage disposal and enhance operational efficiency. This article examines the impacts, challenges, and future directions of computerized garbage disposal systems, emphasizing their potential to foster a more sustainable future. Smart waste management systems (SWMS) represent a cutting-edge approach, leveraging technology to optimize waste collection and disposal processes. GPS-enabled SWMS have emerged as a significant innovation, allowing cities to monitor, control, and enhance waste management operations with remarkable precision.

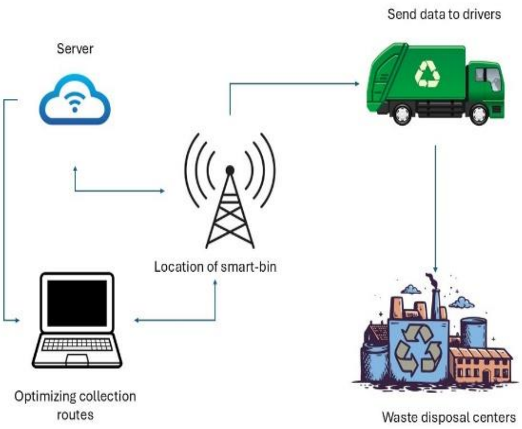

Figure 1. Smart waste management system

LITERATURE REVIEW

Tripathi *et al*., 2018 developed a smart dustbin system for metro stations using RF tags, an RF reader, ultrasonic sensors, motors, an Arduino, and a Raspberry Pi. Powered by a solar panel, this cloud-based system cuts routine bin checks, promoting environmental sustainability. Rohit *et al*., 2018 created a smart dustbin model with two bins, in smart city public areas, Bin A and Bin B work together, with Bin B activating only when Bin A is full.

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Ultrasonic and IR sensors monitor rubbish levels and obstacles, and a GSM system sends data to the control room to prevent overflow and manage the bins effectively. Nehete *et al.,* 2018 designed an IoT-based smart garbage can that uses IR rays to monitor waste levels and sends notifications via GSM when full, helping maintain clean environments and prevent virus spread. Kolhatkar *et al.,* 2018 replaced the Node MCU ESP8266 platform with a system that wirelessly sends email notifications when bins are full, using proximity sensors to detect obstacles and a sound sensor to monitor waste levels, with status displayed on an LCD interface.

Sunny *et al*., 2019 designed a smart trashcan system using a pre-trained CNN, AlexNet, for object recognition, achieving 96% accuracy. The system assigns recycling values to waste items, encouraging usage by allowing waste exchange and potentially offsetting operational costs. Praveen *et al.,* 2020 constructed an intelligent bin with an ESP8266 module and ultrasonic sensors, sending data to a Raspberry Pi for display on a monitor to optimize waste collection by indicating specific homes for pickup. Kumar *et al.*, 2017 proposed an IoT-based trash management system that uses sensors to monitor bin levels and sends updates *via* GSM and GPRS, contributing to cleanliness through a mobile application. Chaudhari *et al.,* 2019 developed a smart container using a Raspberry Pi, sound sensor, GSM module, and weight sensor to monitor bin levels and trigger alerts to authorities when full, aiding in waste collection via robotic components. Mishra *et al*., 2022 developed an IoT-SWM model for predictive waste management, prioritizing bin emptying based on sensor data, achieving 95.8% accuracy in alert notifications using a random forest algorithm.

REFERENCE TABLES FOR SMART WASTE MANAGEMENT SYSTEM

Table 1. IOT and smart bins

Authors and year	Focus of study	Key contributions
Chee Ping et al., 2020	IoT-based smart dust bin	Designed using Arduino Uno and ESP8266 with real-time data integration *via* ThingSpeak and IFTTT; user feedback showed high satisfaction.
Ashwan et al., 2021	Smart bin with solar power	Integrated ultrasonic sensors, servo mechanisms, and solar power for wet and dry waste management in public spaces.
Pardini et al., 2020	IoT-based waste bin monitoring	Used sensors with a one-year lifespan, focusing on real-time monitoring and citizen involvement through apps.
Sheng et al., 2020	LoRa and AI-based smart bin	Developed for waste classification and fill level detection using tensor flow AI.
Rahman et al., 2022	IoT and deep learning for waste management	Achieved 80% success in classifying biodegradable waste with IoT systems and deep learning.

Table 2. AI and machine learning

Authors and year	Focus of study	Key contributions
Gunaseelan et al., 2023	Enhanced ResNeXt architecture	Achieved 98% accuracy in waste identification with a three-section smart bin powered by solar energy.
Joshi et al., 2016	Cloud computing and WSNs for waste monitoring	Used machine learning algorithms for enhanced waste monitoring with a stack-based approach.
Duhayyim et al., 2022	IDRL-RWODC model for smart cities	Achieved 0.993 accuracy in object detection and classification with DRL and Mask RCNN.
Mahajan et al., 2017	Real-time waste monitoringsystem	Optimized collection routes with load and humidity sensors using ML techniques, reducing fuel costs.

Table 3. Innovative platforms and technologies

Authors and year	Focus of study	Key contributions
Catania et al., 2014	Smart-m3 platform	Enabled real-time fill level measurements and rewarded recycling behavior with 'green points'.
Paturi et al., 2021	Blockchain-based SWMS	Demonstrated transparency and scalability using smart contracts on the Matic network.
Thieme et al., 2012	BinCam for recycling	Used social accountability and emotional triggers like guilt to encourage recycling *via* a Facebook-integrated trashcan.

Table 4. Transport and resource optimization

Authors and year	Focus of study	Key contributions
Lella et al., 2017	GIS for waste transport optimization	Achieved a 59.12% reduction in travel distance and identified ideal transport locations in Vellore, India.
Folianto et al., 2015	Wireless mesh network for smart bins	Minimized power consumption with duty-cycling techniques; tested in outdoor environments.
Mamun et al., 2016	Real-time monitoring for waste bins	Optimized collection routes using wirelessly transmitted data.

RESULTS AND DISCUSSION

Table 5.

Section	Aspect	Details
Merits of Implementing SWMS	Enhanced efficiency	GPS-enabled SWMS improve waste collection by using real-time tracking and optimized routing, significantly reducing collection time.
	Cost reduction	Integrating GPS into waste management systems lowers operational costs by creating efficient routes, reducing fuel consumption, and cutting labor expenses.
	Waste bin monitoring	Enables real-time monitoring of garbage bins, preventing overfilling and minimizing litter and environmental pollution.
	Sustainability	Supports sustainability by cutting greenhouse gas emissions and fuel consumption through optimized routing, leading to a smaller carbon footprint.
	Resource allocation	Enhances efficient use of fleets and personnel by optimizing vehicle deployment, reducing costs and improving service.
	Real-time insights	Continuous monitoring provides insights into waste generation patterns, improving resource planning and sustainable waste management practices.
Future scope of smart waste management implementation	Intelligent waste management	Future systems will incorporate sophisticated sensors for real-time monitoring of fill levels, waste composition, and hazards like strong odors, improving collection schedules and cost savings.
	Data analytics & machine learning	Advanced analytics and machine learning will optimize route mapping, predict waste patterns, and assist in city planning for waste reduction strategies.
	Robotics & AI in sorting	Automated systems with image recognition and tactile sensors will enhance the efficiency and accuracy of sorting recyclables, increasing recycling rates and reducing contamination.
	Renewable energy integration	Innovations like kinetic energy harvesters and biogas generators will improve the energy self-sufficiency and environmental sustainability
	Advanced waste-to-energy technologies	New methods, including plasma gasification and engineered bacteria, will create cleaner and more efficient ways to convert waste into high-value products like biofuels or biodegradable plastics, advancing environmental goals.

Analysis of smart waste management systems highlights predictive maintenance as a critical driver of operational and environmental efficiency. IoT sensor data enables predictive algorithms to detect equipment anomalies from compactor malfunctions to lid failures before breakdowns occur, reducing downtime, maintenance costs, and service disruptions while extending infrastructure lifespan. This proactive approach also supports sustainability, optimized resource allocation, fewer emergency repairs, and reduced emissions from maintenance activities collectively lower the ecological footprint of waste operations. By aligning operational reliability with environmental stewardship, predictive maintenance emerges as a dual-purpose innovation for modernizing urban waste systems.

CONCLUSION

Looking ahead, the implications of these advancements are far-reaching:

1) *Environmental impact:* Smart waste management systems have the potential to significantly reduce carbon emissions associated with waste collection and processing. By optimizing routes and improving recycling rates, these systems could play a crucial role in cities' efforts to combat climate change.

2) *Public health:* Real-time monitoring and rapid response capabilities of smart systems could prevent the build-up of waste in public areas, reducing the risk of disease transmission and improving overall urban hygiene.

3) *Resource efficiency:* As waste-to-energy technologies advance, smart systems could turn our waste streams into valuable resources, contributing to the circular economy and reducing dependence on virgin materials.

4) *Urban planning:* The data gathered from smart waste management systems will provide invaluable insights for urban planners, potentially influencing future city designs to better accommodate efficient waste handling.

5) *Behavioral change:* Through increased public engagement and awareness, these systems have the potential to drive long-term changes in consumer behavior, promoting more responsible consumption and disposal practices.

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