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# Iot-Based Smart Waste Collection and Utilization of Segregated Waste as Primary Material for Road Construction

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## Abstract
*Urbanization, by its nature, is defined as a process where the vast majority of the world's population is moving into cities during this century. This rapid rate of urbanization will significantly increase municipal solid waste generation over time, creating a significant number of challenges for traditional waste management systems (traditional collection methods lack real-time monitoring capabilities; the collection method results in overflowing bins within the urban landscape; citizens suffer from exposure to environmental pollution, and ultimately, sanitation workers are put at risk due to Health & Safety risk factors on the job). This project presents a solution through the combination of an Internet of Things (iot) Smart Waste Collection & Segregation System, combined with the recycling of Segregated Waste through its use in road construction. The proposed system utilizes an assortment of sensors (ultrasonic, moisture, metal, and gas) which provide automated integration with a Microcontroller; the system monitors the type of waste being produced and provides automated monitoring of the level of waste within a given waste bin, all while communicating real-time data, via Wireless Communication Modules, with appropriate authorities so that timely collection of the waste is available. The proposed automated collection process will ultimately eliminate much of the manual labour currently needed for segregation at the source and will enable increased efficiencies to recycle what is produced while reducing the need for new construction methods (for example: the recycling of segregated plastic through the Recycling of plastic while the incorporation of segmented plastic in the bituminous base for pavement will prolong cement base durability to a significantly higher degree than that of current construction methods). The integrated approach presented by this project will provide both increased efficiencies to existing waste management systems and further support sustainable Infrastructure Development efforts around Smart City Initiatives through the recycling of waste outside of landfills and minimizing any negative effects associated with the accumulation of urban produce as solid waste.*
**Keywords:** *Arduino UNO; Internet of Things; IR sensor; Moisture sensor; Motor; Segregation.*

## 1. Introduction
As cities grow rapidly, the amount of waste they generate also grows rapidly, placing huge demands on traditional systems that are already strained. Large amounts of manual collection and schedule-based systems limit real-time monitoring and accurate segregation of waste. This has resulted in overflowing bins, pollution to our environment, and increased health risks. In addition, landfill waste not only produces leachate (liquid that comes from the Waste), but it also produces gases that leachate into groundwater and cause soil degradation. Most urban areas have "rag-pickers" who manually pick through waste to find recyclable items for reuse. This poses hazards to their health due to the diseases and other issues associated with recycling. While some industrial facilities perform segregation, source segregation is the most effective way to achieve voluntary compliance with disposing of recyclables. Recent advances in technology have introduced smart

waste management methods that use sensors, embedded control devices, and wireless communication. Smart bins which automatically monitor fill-levels and automate the segregation of wet waste, dry waste, and metal waste are possible thanks to iot. Recycling plastics for use in the production of roads reduces the need for fossil fuels to create new asphalt as well as increases the life span of our roads. This project is looking at how iot is being integrated with traditional waste monitoring systems to create both environmentally-friendly roads and provide the operational efficiencies needed to promote the creation of smart cities. [1]

## 2. Existing system and problem statement

### 2.1.Traditional waste collection

The current system of waste collection is essentially a manual process that utilizes fixed collection schedules. Waste bins are emptied either on a pre-determined schedule or at a previously agreed time, regardless of their actual fill levels. This creates both fuel inefficiencies and increased operational expenses due to the waste being collected too early or too late resulting in environmental pollution due to the waste being thrown into the road/sidewalk. In addition to these issues, fixed collection routes do not account for differences in the rate of waste generation within commercial districts, retail establishments, and residential neighbourhoods – creating either wasted collection trips or delayed collection services. The lack of real-time monitoring of the status of bins means that local governments cannot monitor dynamic conditions affecting bin status, affecting their decision-making process and service delivery.

### 2.2.Problem statement

Waste segregation in traditional systems is largely dependent on manual labor, especially ragpickers. The segregation process is carried out after waste collection, which increases exposure to hazardous materials. Workers are prone to health risks such as respiratory infections, skin diseases, and other infections due to direct contact with mixed waste. Furthermore, improper segregation reduces recycling efficiency and increases landfill dependency. Manual segregation is time-consuming and inconsistent, as it depends on human judgment and working conditions. In many cases, recyclable materials get contaminated with wet or organic waste, making recovery difficult and economically unviable. Lack of awareness among the public about proper waste disposal practices further worsens the situation. As a result, valuable recyclable resources are lost, and the overall sustainability of waste management systems is compromised. [2]

### 2.3.Limitations

The existing waste management system suffers from several limitations, including lack of real-time monitoring, inefficient route planning, dependency on manual labor, and poor waste segregation practices. There is no automated mechanism to monitor bin status or notify authorities when bins are full. Additionally, conventional road construction relies heavily on natural resources like bitumen without utilizing recyclable waste materials, contributing to environmental degradation. Another major limitation is the absence of data-driven planning. Without proper data collection and analysis, municipal authorities cannot predict waste generation patterns or optimize resource allocation. The system also lacks integration between waste management and recycling industries, leading to increased landfill accumulation. Environmental concerns such as greenhouse gas emissions, groundwater contamination due to leachate formation, and increased carbon footprint further highlight the inefficiency of the traditional approach. Therefore, there is a strong need for a smart, automated, and sustainable waste management solution. [3]

### 2.4.Motivation

Urbanisation & population growth has significantly increased the amount of municipal solid waste generated in our cities. The existing systems of waste management are unable to deal with the rapidly increasing amounts of MSW and again cannot do so, resulting in overflowing bins, environmental pollution, bad odour. Manual collection/monitoring is inefficient, labour-intensive and poor at provide real-time tracking of what is collected and where it is from. These conditions create operational inefficiencies and increase the burden of operational management on municipal authorities. The next major concern is the improper segregation of waste. The properly segregated waste provides the maximum recycling efficiency and one of the greatest opportunities for reducing the quantity of waste going to landfills - as well as the quantity of waste being collected. Therefore, there is a need for an automated waste segregation system to be developed which performs this function at source and reduces the amount of direct involvement by humans. Thus, such an automated system would provide a safer environment for those who are currently engaged in manual waste segregation. Additional problems associated with waste management include the huge volumes of natural resources required for road construction. Additionally, plastic has become a major source of environmental pollution because it does not breakdown the motivation behind this project is to integrate smart waste monitoring, automated segregation, and sustainable infrastructure development into a single system. By combining iot technology with plastic waste utilization in road construction, the proposed system aims to reduce landfill waste, improve recycling efficiency, lower construction costs, and promote environmentally sustainable urban development. This approach supports the concept of smart cities and encourages waste to be treated as a valuable resource rather than as a burden [4]

## 2.5.Methodology

The proposed system is an iot-based smart waste collection and segregation system integrated with sustainable road construction methodology. The primary objective of the system is to monitor waste levels in real time, automatically segregate waste at the source, and utilize segregated dry waste (especially plastic) as a primary material in road construction. The system consists of smart bins equipped with sensors, a microcontroller unit, communication modules, and a cloud-based monitoring platform. The sensors detect the type and level of waste inside the bin, and the microcontroller processes the sensor data to control segregation mechanisms. The collected data is transmitted to a centralized server using wireless communication technologies such as GSM or Wi-Fi. Municipal authorities can monitor bin status remotely and schedule collection efficiently. Figure 1.

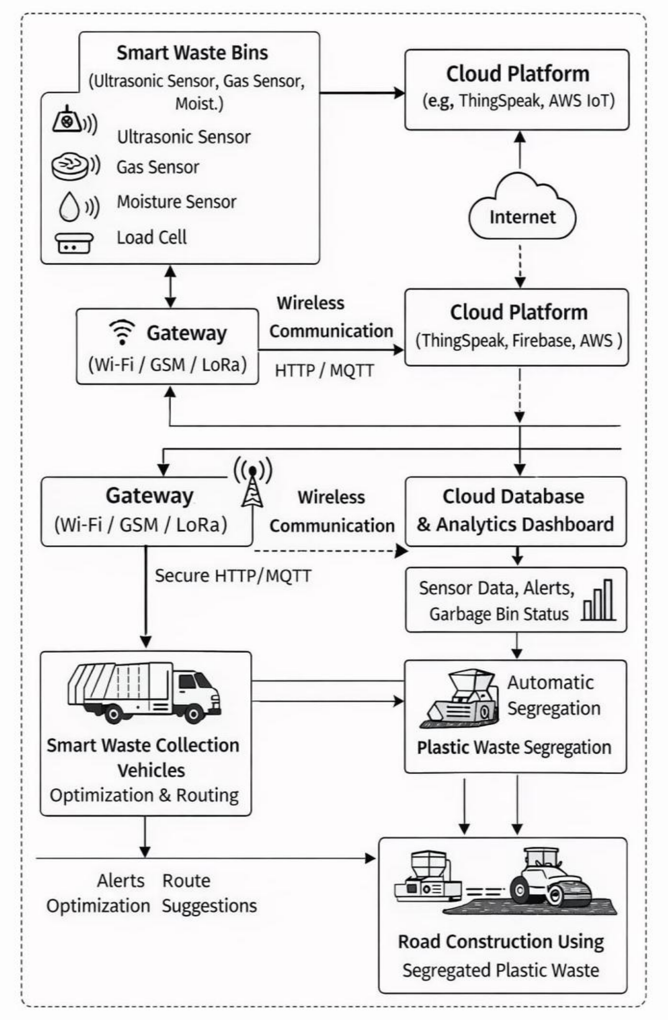


**Figure 1 Flow Process**

## 2.6.Ultrasonic Sensor

The ultrasonic sensor is used to measure the level of waste inside the bin by operating on the principle of echo reflection. It emits high-frequency ultrasonic sound waves, typically around 40 khz, which travel through the air and reflect back after hitting the surface of the waste. The sensor calculates the time taken for the echo to return and determines the distance between the sensor and the waste surface using the speed of sound. As the waste level increases, the measured distance decreases, allowing the system to estimate the fill percentage of the bin. This real-time level monitoring helps prevent overflow and enables timely waste collection through alert notifications sent by the microcontroller


## 2.7.Moisture sensor

The moisture sensor is used to differentiate between wet and dry waste based on electrical conductivity. It consists of two conductive probes that measure the resistance between them when waste comes into contact. Wet waste contains water, which increases conductivity and reduces resistance, producing a higher analog output value, whereas dry waste shows lower conductivity. The microcontroller reads these values and classifies the waste accordingly, ensuring proper segregation at the source. This improves recycling efficiency and supports composting processes by preventing contamination of recyclable dry materials. [5]

## 2.8.Gas Sensor

The gas sensor is used to detect harmful gases generated from decomposing waste, such as methane, ammonia, or other toxic gases. It operates based on changes in the electrical resistance of a sensing element when exposed to specific gases. When harmful gases are present inside the bin, the chemical interaction between the gas molecules and the sensor's sensitive material alters its conductivity, producing a corresponding voltage change at the output. This signal is read by the microcontroller and compared with predefined safety thresholds to determine the concentration level of the gas. If the gas concentration exceeds safe limits, the system can trigger alerts to prevent potential health hazards, reduce the risk of fire or explosion (in the case of methane), and ensure a safer waste management environment.


## 2.9.Microcontroller (Arduino)

The Arduino microcontroller acts as the central control unit of the smart waste management system, coordinating the operation of all sensors and actuators. It continuously receives input signals from the ultrasonic, moisture, IR, metal, and gas sensors, processes these signals based on programmed logic, and makes decisions for waste classification and bin monitoring. The microcontroller compares sensor readings with predefined threshold values to determine whether the waste is wet, dry, metallic, or hazardous, and accordingly controls the motor mechanism to direct the waste into the appropriate compartment. It also monitors the fill level of the bin and activates the communication module to send alerts or status updates when the bin reaches its maximum capacity. By executing embedded instructions stored in its memory, the Arduino ensures real-time operation, automation, and efficient coordination of the entire system.

## 2.10. Servo motor

The servo motor is used in the smart waste management system to control the mechanical movement required for waste segregation. It operates

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based on pulse width modulation (PWM) signals received from the microcontroller, which determine the precise angular position of the motor shaft. Unlike ordinary DC motors, a servo motor provides accurate position control, typically within a range of 0° to 180°, making it suitable for directing waste into specific compartments such as wet, dry, or metallic bins. When the microcontroller classifies the type of waste based on sensor input, it sends a control signal to the servo motor, which rotates to a predetermined angle to open or align the appropriate section of the bin. This precise and controlled movement ensures reliable and automated segregation while minimizing mechanical errors and power consumption.

## 3. Software implementation

### 3.1. GSM Module:

The GSM module is used in the smart waste management system to enable wireless communication between the smart bin and the municipal monitoring system. It operates using cellular network technology to transmit data such as bin fill level, waste status, and alert notifications to a remote server or authorized personnel. When the ultrasonic sensor detects that the bin has reached a predefined threshold level, the microcontroller sends a command to the GSM module to transmit a message containing the bin status and location details. This real-time communication helps authorities schedule timely waste collection, reduce overflow situations, and optimize transportation routes. The GSM module ensures continuous remote monitoring and supports the implementation of an efficient and responsive smart city waste management system. Figure 2.

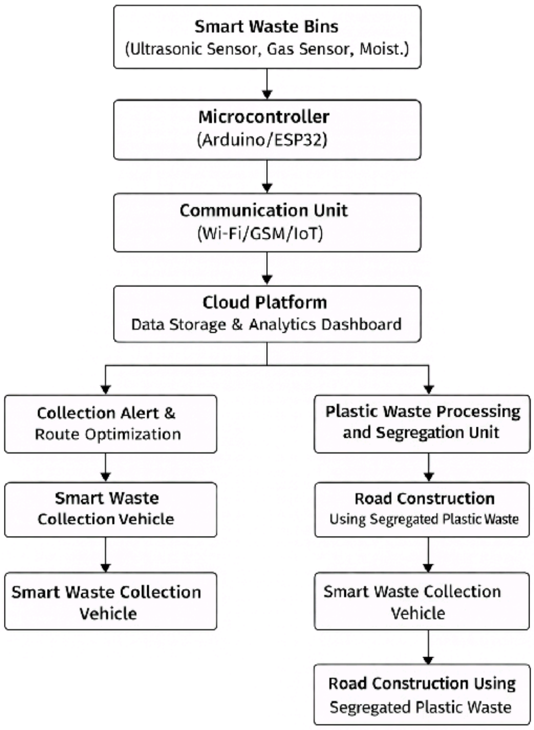


**Figure 2 Flow Chart**

## 4. Results and Discussions

Testing has been done on this iot-based smart collection and segregation system to assess the performance of the system for real-time monitoring of waste as well as accuracy of automated separation, and efficiency in communication. Monitoring of waste bin fill level was accomplished successfully using ultrasonic sensors. The sensors detected the threshold conditions for the fill level and generated alerts in a timely manner, eliminating overflow situations by informing the responsible party once the bin reached the fill capacity. The result of real-time monitoring was a decrease in unnecessary collection trips improving overall operational efficiency. Moisture and metal sensors proved to be reliable for determining whether waste was wet, dry, or metallic. Accurate source separation was achieved based on the input from the sensors to the actuator (servo- motor) utilized to direct waste into the correct compartments. Significant reductions in the level of contamination of recyclable materials due to automated separation at the source occurred along

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with significantly less manual labor required to separate the waste. Thus improving recyclability and providing improved working conditions for sanitation staff due to reduced exposure to mixed waste. The GSM communications module was successfully used to transmit bin status data to the monitoring platform which provided for remote access to the monitoring system and real-time status tracking. Furthermore, segregated plastic waste has been processed into bituminous road construction material. Results from the experiments showed that bitumen modified with plastic improved binding properties, increased durability, reduced the likelihood of cracking or forming ruts, and decreased the permeability of water through the surface. This demonstrates that combining waste management with road construction provides both environmental and infrastructure-related benefits. All of these results provide evidence that this system will enhance the efficiency of waste separation, decrease pollution to the environment, provide data-oriented waste collection planning tools, and facilitate the establishment of sustainable infrastructure growth. The integration of iot technology and plastic waste creates a viable and low-cost solution for smart cities.

## 5. Conclusion

The iot-based smart waste collection and segregation system has been developed as part of the project, which uses segregated waste in road construction. This system substantially reduces reliance on manual methods of waste management and introduces an effective solution to the four main problems of traditional waste management: manual monitoring, insufficient segregation, overflowing bins, and polluting the environment. The system uses sensors, such as ultrasonic, moisture, metal, and gas sensors, as well as a microcontroller and communication modules, to enable real-time monitoring of bins, automatic classification of waste, and remote transmission of data to the appropriate authorities. Through automation, the need for human intervention has been greatly reduced and the health risk of sanitation workers has been minimized. Real-time alerts on when to empty bins allow for better collection efficiency and optimal use of resources. Also, the system helps reduce fuel consumption and operational costs. Additionally, using segregated plastic waste for bituminous road construction is an environmentally friendly solution because it reduces the amount of waste sent to landfills and the reliance on virgin construction materials. In conclusion, the integration of iot technology and sustainable infrastructure development provides a viable solution to the challenge of modern management of urban waste. The proposed system promotes urban waste management and is consistent with smart city initiatives, improves recycling rates, helps preserve the environment, and converts waste into an asset. It is anticipated that with continued scalability and optimization, the system can be implemented broadly in urban environments to achieve efficient, safe, and sustainable waste management.

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