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AWPRATOR: Autonomous Waste Picking Robot and Tracking of Routes

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Abstract

Traditional waste management systems, especially in urban and semi-urban areas, relies heavily on manual methods like manual collection of waste, and fossil-fuel based garbage trucks. These methods often face many challenges such as inefficient high dependency on human labor, inefficient planning of routes, health risk for sanitation workers, lack of adaptability, real-time decision making. With the increase in the number of smart cities, the need for intelligent, autonomous, and eco-friendly solutions is must. This paper introduces AWPRATOR (Autonomous Waste Picking Robot and Tracking of Routes), a novel approach to automate waste collection through sensor-based navigation, robotic arm for garbage handling, and inbuilt segregation mechanism. It integrates electric mobility and real-time monitoring, ensuring lesser human intervention and improved hygiene standards. The design is modular and scalable, making its deployment suitable for congested urban streets and larger municipal cities as well. The proposed system bridges the gap between semi-automated waste collection and the futuristic fully autonomous, adaptive waste management in smart cities.

Keywords: Autonomous waste picking, sensor-based navigation, robotic arm, inbuilt segregation, electric mobility, real-time monitoring, adaptive waste management

INTORDUCTION

Waste management has always been a critical challenge for both developed and developing nations. Traditionally, waste collection in urban and semi-urban areas has relied heavily on manual labor and fossil-fuel-powered garbage trucks, where sanitation workers are directly exposed to hazardous conditions and unhygienic surroundings. These conventional systems often face multiple problems such as irregular waste collection schedules, inefficient route planning, health risks to workers, and high dependency on human involvement [1]. As urban populations grow and the volume of waste increases, these issues not only put pressure on municipal corporations but also contribute to environmental degradation through carbon emissions and improper disposal methods. Over the years, several attempts have been made to improve waste collection systems.

Mechanized garbage trucks, GPS-enabled route mapping, and semi-automated bin lifters were introduced in many cities. While these solutions brought some improvement, they still remained limited in autonomy and continued to depend on human drivers and operators. Furthermore, these trucks usually run on diesel-based engines, adding to pollution concerns [2]. In addition, waste

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segregation, which is a crucial step in recycling and sustainable management, is mostly performed manually in such systems, further risking human health.

With the rise of smart cities and Industry 4.0-based automation technologies, researchers have started exploring robotics, IoT, and AI to make waste collection more autonomous, efficient, and sustainable [3]. However, most of the current robotic waste management solutions are either in prototype stage or highly localized with limited adaptability. A scalable, eco-friendly, and modular solution is still missing in large-scale deployments.

To tackle these issues, this paper introduces AWPRATOR (Autonomous Waste Picking Robot and Tracking of Routes), a novel system designed to automate waste collection through sensor-based navigation, robotic arm for garbage pickup, and inbuilt segregation mechanisms. Unlike traditional garbage trucks, AWPRATOR is fully electric, reducing carbon emissions while also ensuring sustainable operations. It operates autonomously using a combination of IR/Ultrasonic sensors, and microcontrollers to navigate routes, detect waste bins, and perform robotic collection of waste materials using the robotic arm without any human intervention. The system is also capable of segregating waste internally, reducing the health risks for sanitation workers and increasing recycling efficiency.

One of the unique features of AWPRATOR is its modular and scalable design, which allows it to operate in congested urban lanes, semi-urban areas, and even industrial zones.

Through real-time monitoring and wireless connectivity, municipal authorities can track vehicle performance, bin fill levels, and optimize operations. Furthermore, future enhancements can include predictive route optimization algorithms and AI-based waste detection, making it a step closer towards a fully autonomous smart waste management ecosystem [4].

This paper presents the system design, simulation results, and a comparison with the older methods of waste collection and management, which will ultimately present a comprehensive analysis and perspective regarding the waste management on small and large scale.

Early Waste Management Methodologies: The Conventional/Traditonal Way of Managing the Waste

Over the past decades, waste management practices, particularly in urban and semi-urban regions, have largely relied on traditional manual methods such as hand-picking, sweeping, and transportation through diesel-powered garbage trucks. These approaches, although functional, have faced severe limitations in terms of efficiency, health safety, and sustainability. In most municipalities, waste is collected manually by sanitation workers, loaded into trucks, and then transported to dumping sites or landfills. While this system has been operational for many years, it suffers from several critical drawbacks including lack of proper route planning, delayed collection schedules, exposure of workers to hazardous waste, and high fuel consumption [1].

Earlier innovations attempted to modernize waste collection using semi-automated vehicles with hydraulic lifters and compactors. While these machines reduced the manual lifting burden, they did not eliminate the dependence on human drivers and operators. In addition, these trucks continued to rely on fossil fuels, contributing to urban air pollution and higher carbon footprints [2]. Another significant limitation has been waste segregation. Despite repeated emphasis from municipal authorities, segregation of waste into biodegradable, recyclable, and hazardous categories is still carried out manually in most cities, putting sanitation workers at risk of infections and toxic exposure [5].

In the context of smart city initiatives, some efforts have been made to integrate GPS-based routing and IoT-enabled smart bins. These technologies allow for real-time monitoring of bin fill levels and route optimization. However, their implementation has been limited to pilot projects in certain metropolitan regions and they lack full autonomy. These systems still rely heavily on centralized monitoring centers and manual intervention for decision- making [4]. Moreover, the cost of large-scale deployment and maintenance of such IoT-enabled systems has also been a barrier, especially for municipalities with budget constraints.

Thus, while early systems contributed to partial improvements, they remain far from efficient and sustainable. They are labor-intensive, human-dependent, and energy-inefficient, leaving large gaps in safety, adaptability, and environmental sustainability. These drawbacks highlight the urgent need for more autonomous, modular, and eco- friendly solutions such as AWPRATOR, which not only automates the process of garbage collection and segregation but also minimizes human intervention, reduces health hazards, and integrates with smart city ecosystems for real- time monitoring and scalability.

AWPRATOR: THE NEW, EFFICIENT, TECHNOLOGICAL SOLUTION FOR PRESENT DAY WASTE MANAGEMENT

The transition from traditional waste collection systems to autonomous solutions like AWPRATOR marks a significant step forward in urban sustainability and smart city development. With the rapid growth of urbanization and the increasing demand for cleaner cities, technologies such as sensors, robotic arms, and intelligent navigation systems are becoming key factors for modern waste management operations. Here, a collaborative approach between human operators and autonomous robotic systems is essential for achieving efficiency and safety.Collaboration in this context refers to minimizing direct human involvement in hazardous tasks while still allowing supervision and system training. In the past, most waste collection processes were heavily manual, with trucks and workers following fixed schedules irrespective of bin status or fill levels. However, AWPRATOR introduces adaptive intelligence to the process. Equipped with ultrasonic and IR sensors, robotic arms, and an integrated control system, the vehicle not only follows pre-defined routes but also learns and adjusts based on real- time conditions.

Unlike older garbage trucks that simply follow instructions, AWPRATOR is designed to detect, adapt, and respond. For instance, when deployed in a locality, the system does not just collect waste but also updates its internal data regarding bin fill levels, waste type, and time of collection. Over time, this continuous collection of data helps the system train itself, optimizing routes and reducing redundant travel. This learning capability allows the system to enhance operational efficiency and minimize energy consumption.

Another major advantage of this transition is the introduction of autonomous waste segregation. Traditional collection required human workers to manually separate biodegradable and recyclable waste, exposing them to hazardous materials. AWPRATOR, on the other hand, integrates basic segregation mechanisms within the robotic handling process, ensuring safer and faster operations. While humans remain in supervisory roles, the robotic system takes the lead in executing repetitive and hazardous tasks.To ensure real-time adaptability, AWPRATOR can employ rule- based logic and lightweight AI models that help in predictive route adjustments and bin prioritization. This not only improves efficiency but also aligns with the vision of smart and self-learning urban infrastructures.

Automation in Waste Management

As the amount of waste which is generated is increasing rapidly, there is a requirement to manage it as well. So to manage it more efficiently and being less reliant on human personnel, automation plays an important role in this (Figure 1).

The automated machines can perform various operations, specifically considering robotics, it can help in in collection, dumping and sorting. They are also useful in lifting waste materials and segregating them [6].

ALGORITHM FOR ROBOTIC ARM WASTE PICKUP AND SEGREGATION

1. Procedure ROBOTIC_ARM_PICKUP(target bin, waste type)
2. Move arm to a pre-pickup position above bin
3. Align gripper using the sensor feedback
4. Lower the arm until the sensor triggers
5. Close gripper and measure the load cell weight
6. if weight <= max safe load then
7. Lift arm to safe height
8. Move to segregation chamber
9. Release waste into chamber
10. else
11. abort the pickup
12. Return arm to the initial position

End procedure

Figure 2 Shows the manual vs robotic method used.

Figure 1. Capabilities of robots to collect and segregate waste materials.

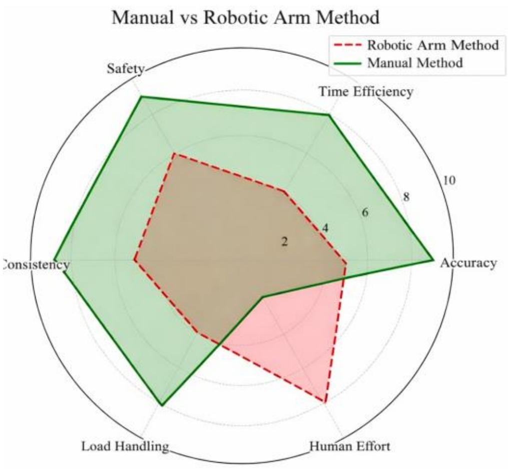

Figure 2. Radar chart for comparison of the traditional manual method and using robotic arm for waste collection, deposition and segregation based on the parameters such as safety, time efficiency, accuracy, effort, load handling, and consistency.

ALGORITHM FOR OVERALL OPERATION BY AWPRATOR

1. Start the system and load predefined route
2. Vehicle moves along planned path
3. Continuously scan surroundings for garbage bins
4. if no garbage detected
5. keep moving
6. if garbage detected
7. stop vehicle
8. robotic arm moves towards waste
9. picks waste and place in collection compartment
10. segregate waste into categories if required
11. arm returns to initial position
12. Vehicle resumes movement to next point
13. Repeat process until route completed
14. Move to dump yard after finishing the route
15. Unload collected waste
16. Vehicle resets and repeats the process everyday (Figure 3)

WORKFLOW OF AWPRATOR: THE WAY HOW THE WASTE COLLECTION VEHICLE WILL WORK

Since in this kind of waste collection where automation is the centralized part of the system and there is no intervention of human personnel, there should be a proper workflow and steps to be followed so that there is no room for error or any kind of discrepancies. The movement of the vehicle, the working of the robotic arm, and the way of collection is defined in this workflow (Table 1).

In the workflow of the AWPRATOR (Figure 4), the process starts with the movement of the vehicle in which a pre-defined path/route is fed in the vehicle's software and based upon that the vehicle moves to the desired locations for the picking of waste materials.

The vehicle is capable of detecting the obstacles and based on that it can divert its route and move ahead. The most prominent feature of the vehicle is that it is capable of detecting garbage which is present on the roadside or where the garbage is being dumped and is able pick up the garbage using a robotic arm.

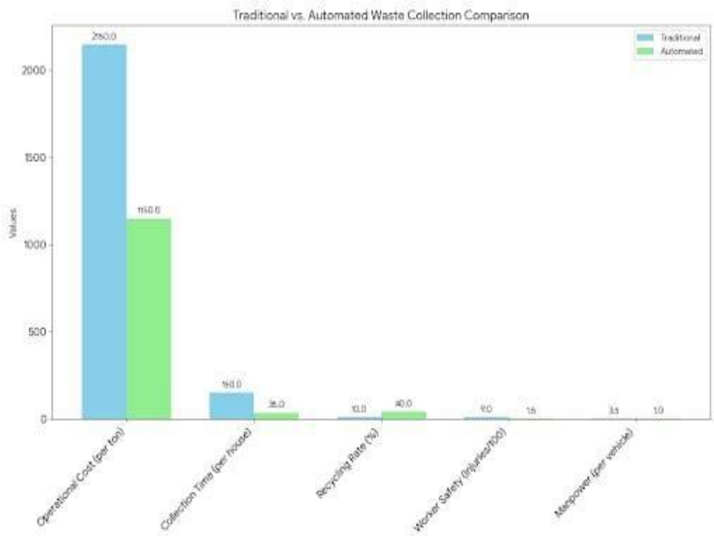

Figure 3. A comparison graph for manual waste collection and automated waste collection based on the parameters such as operational cost, collection time, recycling rate, worker safety, and manpower requirement.

Table 1. A Comparison for waste collection process done by manual method and automated method

Parameters	Traditional/Manua l Method	Autonomous Method
Manpower (per vehicle)	3.5	1.0
Operational Cost (per ton)	2150.0	1150.0
Collection Time (per house)	150.0	35.0
Recycling Rate (%)	10.0	40.0
Worker Safety	9.0	1.5

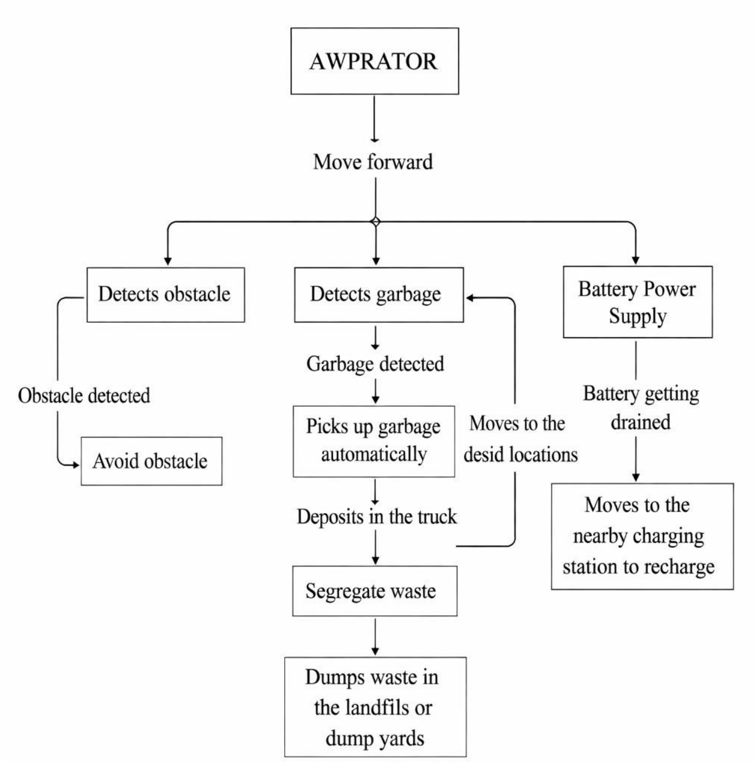

Figure 4. Workflow of the AWPRATOR for movement, autonomous waste collection, dumping, and battery management.

It then deposits the garbage inside the truck and the truck consists of an in-built segregation mechanism, which helps in segregating the waste materials into separate categories like medical waste, electronic waste, biodegradable and non-biodegradable waste, etc. and after collecting all the waste from the localities and desired locations, it then moves towards the dump yards or landfills where the garbage will be dumped.

Additionally for future part and as a part of eco-friendly mobility, the vehicle runs completely on electric power and if the battery gets drained or at a very lower level, then it is capable of moving towards the nearest charging station, where it can charge itself and then again continue with the operation.

RESULTS AND DISCUSSIONS

The traditional way of collection of waste is have more human intervention. Whether it is related to driving of trucks, collecting waste, segregating, and dumping, everywhere human personnel is required to manage it properly without any hassle. Since the world is now moving towards automation and everything is getting automated, minimizing the involvement of human in any kind of work, waste management is no exception.

Here are some of the results (assumed as per previous datasets and analysis) about the comparison of traditional waste management with the proposed effective and automated way of waste management, in which there is almost no involvement of human in any kind of operations.

In (Figure 5), the bar chart demonstrates the comparison between different performance parameters such as accuracy, time efficiency, human involvement, and reliability. It shows that how automations makes the waste management process even more efficient than the traditional techniques.

In (Figure 6), the graph illustrates the comparison of operational factors of the traditional and proposed method. It shows that the route efficiency, coverage area of the vehicle and the consistency regarding waste collection and segregation is quite high, whereas in terms of energy consumption, since the vehicle is completely electric powered the energy consumption is quite as compared to the fuel powered vehicles which uses the fossil fuels and causes harm to the environment.

In (Figure 7), the radar chart demonstrates that the autonomous waste handling mechanism shows a superior performance in terms of segregation accuracy, safety, load handling, and speed of the work. Overall it is always at par than the traditional methods.

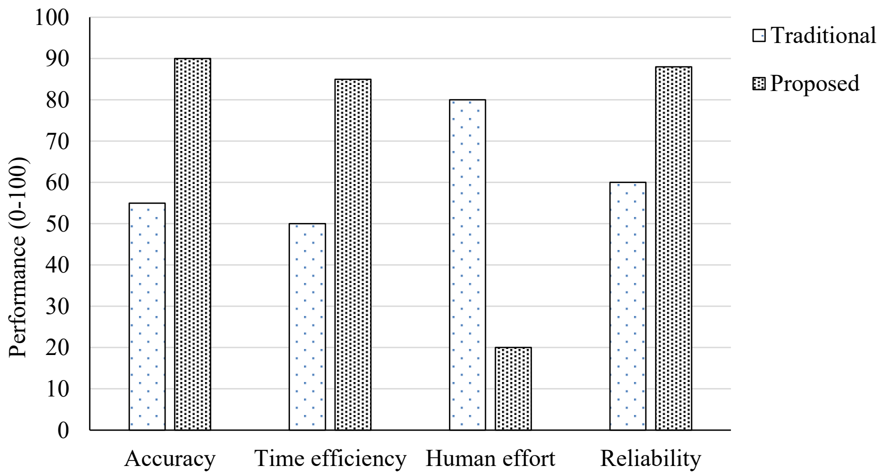

Figure 5. A comparison graph for the performance parameters of traditional methods and the proposed method of waste management.

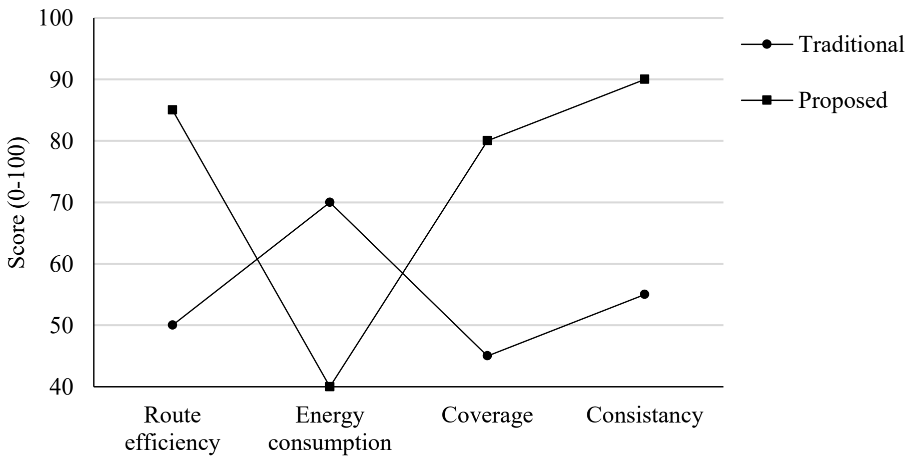

Figure 6. A comparison graph for the operational factors like route efficiency, energy consumption, coverage area, and consistency.

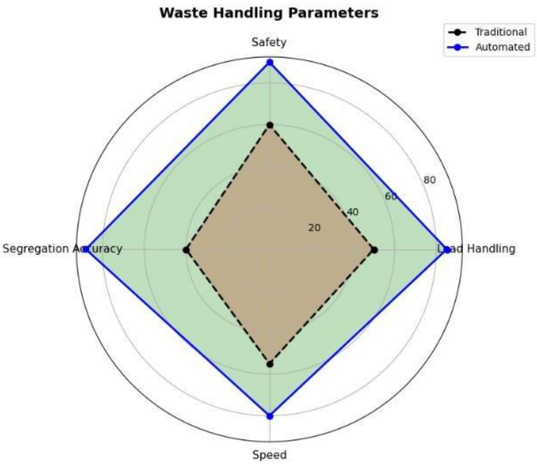

Figure 7. Radar chart for comparison of waste handling parameters (metrics) between traditional and automated waste handling.

CONCLUSION

Waste management is a very crucial aspect not only for a small area, locality or state but for the whole nation and having a proper management technique is a requirement. The transition of the cities towards sustainable and smart has been a prominent development and with that the waste management task has also become a challenging task for the municipal corporations to handle.

No matter how well the systems are structured for the waste management or measures being taken for them, still there are lots of flaws and discrepancies which needs to be analysed and eradicated. Factors such as accuracy, waste collection, reliability, sanitation, segregation, etc. plays a crucial role in terms of the operation.

So the proposed invention of AWPRATOR, is quite effective for the modern day waste management systems. Since it is completely automated from driving, detecting waste materials, collecting them using robotic arm to segregating the waste within the truck and then dumping it in the dumping area. Each and every process is completely autonomous and moreover, the vehicle is completely electric powered, so there is no harm caused to the environment since there is no carbon emission. This invention demonstrates a revolutionary transition towards the field of waste management and opens up the door for future research areas in the field of modern waste management and the use of automation in it.

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