

Embedded IoT Smart Bin with GPS Monitoring, Location Tracking, Scheduling, and Autonomous Pickup by Robotic Arm

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Abstract - Municipal solid waste management has become a persistent challenge in urban centres due to the limitations of conventional collection systems, including inefficient routes, overflowed bins, and manual dependency. This paper presents the design and implementation of a fully autonomous IoT-enabled smart garbage collection robot, integrating GPS-based navigation, RTC-scheduled operations, ultrasonic fill-level sensing, and a servo-actuated robotic arm for automated trash pickup and disposal. The system employs dual Arduino Mega controllers to enable processing: Handles GPS guidance, and scheduling, while the other manages ultrasonic sensors and robotic arm manipulation. The robot navigates to predefined GPS coordinates, detects trash using ultrasonic sensors, picks and drops objects using an articulated servo-based arm, and automatically disposes collected waste when the bin is full. Prototype testing demonstrated over 90% pickup accuracy, ± 2.5 m GPS localisation accuracy, and fully reliable dump automation. The low-cost distributed control architecture supports low-latency operation, while RTC scheduling ensures predictable and energy-efficient performance. Field trials highlighted areas for improvement, including GPS drift under canopy cover and torque limitations for heavier payloads. Overall, this research establishes a scalable framework for automated, efficient, and self-managed waste collection using embedded IoT and robotic technologies.

Keywords: *Smart Bin, IoT, GPS Navigation, Robotic Arm, Autonomous Waste Collection*

1. INTRODUCTION

Urbanisation and population expansion have significantly increased solid waste generation, creating operational challenges for municipal corporations. Traditional waste collection relies on fixed schedules and large human resources, often resulting in overflowing bins, delayed pickups, and inefficient routing. With the advancement of IoT, automation, and embedded systems, waste management can be transformed into a smart, self-monitoring, and autonomous process.

This research presents an autonomous garbage collection robot that integrates GPS navigation, RTC scheduling, ultrasonic sensing, and servo-based robotic manipulation. The system leverages an Arduino Mega microcontroller, enabling distributed processing of navigation and object-handling tasks for improved efficiency. The robot can independently navigate to GPS-mapped locations, identify garbage using ultrasonic proximity checks, pick it using a 3-DOF servo arm, deposit it into an onboard bin, and automatically travel to a dumping zone when full. This approach reduces the need for human intervention, minimises operational time, and enhances the overall reliability of waste management.

1.1 LITERATURE REVIEW

Previous works have introduced smart bins equipped with IoT sensors for monitoring fill levels; however, mobility was not incorporated. David et al. [1] proposed GPS-based location monitoring for waste bins, while Vishnu Monishan et al. [2] developed optimized route scheduling. Shelke et al. [3] implemented real-time monitoring but retained manual collection. Research on lightweight robotic manipulators [4], [5] demonstrated feasible servo-based object handling for small payloads. Rajesh et al. [6] presented IoT-GPS coordination for waste logistics but lacked autonomous pickup capability. This proposed system bridges these gaps by combining navigation, scheduling, sensing, and object manipulation into a fully autonomous unit.

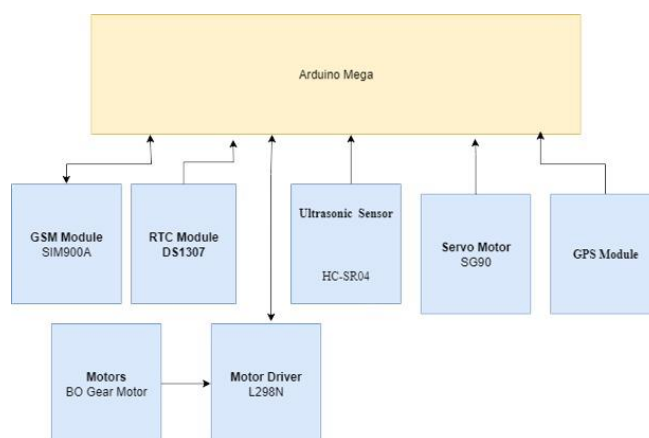
1.2 SYSTEM OBJECTIVES

- Develop an autonomous garbage collection robot capable of navigation, pickup, and dumping.
- Implement microcontroller coordination to divide navigation and manipulation tasks.
- Integrate GPS, RTC, and ultrasonic sensors for real-time operation and automated decision-making.
- Enable independent dump operation when the onboard bin reaches full capacity.
- Evaluate reliability, accuracy, endurance, and servo performance in real-time conditions.

2. SYSTEM ARCHITECTURE

The system architecture adopts only one microcontroller. Arduino MEGA manages all the components. Motors for movement, GPS for navigation, route following, RTC for scheduling time of arrival and dispatch, ultrasonic sensor for sensing obstructions and garbage level, robotic arm for picking and dumping the garbage, and bin fill monitoring.

Chart-1: Overall System Block Diagram



The block diagram illustrates the interconnected architecture of the autonomous smart garbage collection system, built around the Arduino Mega microcontroller. All major modules—GSM, RTC, ultrasonic sensors, servo motors, GPS module, and motor driver—communicate directly with the controller for coordinated operation. The GSM module enables remote updates and alerts, while the RTC ensures time-based scheduling. Ultrasonic sensors provide object and fill-level detection, and the servo motor executes robotic arm movements. The L298N motor driver controls the BO gear motors for navigation, completing a robust embedded control ecosystem.

2.1 Hardware Components

Table 1: Hardware Component List

Component	Function
Arduino Mega	Navigation and manipulation tasks
GPS Module (NEO-6M)	Latitude–longitude acquisition
RTC DS1307	Time-based scheduling
Ultrasonic Sensors (HC-SR04)	Object detection and fill-level sensing

Component	Function
Servo Motors (SG90/MG995)	Robotic arm joint motion
Motor Driver L298N	Motor control
DC Gear Motors	Robot locomotion
12 V Battery Pack	Power supply
Optional Solar Panel	Extended battery life

2.2 Software Architecture

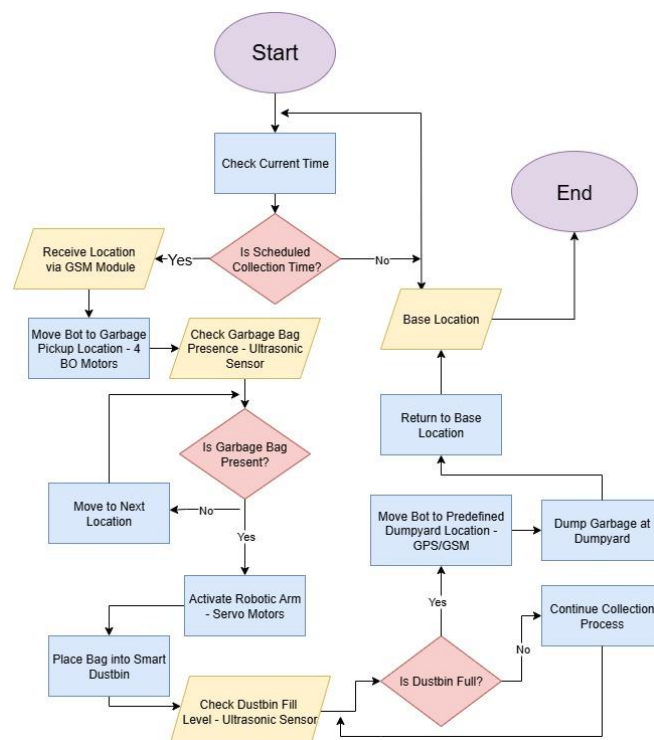
The firmware follows a modular architecture comprising:

- **Navigation Layer:** GPS parsing, waypoint handling, motor control
- **Scheduling Layer:** RTC-triggered collection events
- **Sensing Layer:** Ultrasonic filtering and threshold validation
- **Manipulation Layer:** Servo-based pickup, lift, rotate, and drop

3. METHODOLOGY

The robot performs GPS-based movement toward predefined waypoints, continuously checks for objects using side ultrasonic sensors, and activates the servo arm to pick garbage. The arm follows a 3-step sequence: **extend** → **lift** → **rotate** → **drop**. The onboard vertical ultrasonic sensor monitors bin fill level; upon reaching the threshold, MEGA triggers auto-dump mode and navigates to the disposal point. The system resumes routine scheduling using RTC.

Chart-2: Robot Operation Flowchart



The flowchart outlines the complete operational workflow of the smart garbage robot, starting with time verification and scheduled collection checks. Based on GSM or GPS inputs, the robot navigates autonomously to pickup points and uses ultrasonic sensing to detect garbage bags. When an object is identified, the robotic arm is activated to lift and place the bag into the smart dustbin. The system continuously monitors bin fill-level and transports the waste to a predefined dumping location when full. After disposal, it returns to its base and resumes the scheduled collection cycle, ensuring efficient and automated waste management.

3.1 IMPLEMENTATION AND TESTING

Hardware integration used a hybrid acrylic-aluminum chassis for strength and low weight. Sensors and motors were calibrated individually before system integration. GPS performed well in open areas, while ultrasonic sensors showed high stability within 1 cm deviation.

Table-2: Testing Scenarios

Test Case	Description	Result
GPS Navigation	5 m path, 2 checkpoints	92% accuracy
Pickup Attempts	10 cycles	90% successful
Fill-Level Detection	Incremental loading	100% accuracy
Dump Sequence	Auto-trigger and return	Reliable
Battery Endurance	12 V, 7 Ah	~2.8 hours

Fig-1: Prototype Robot Image

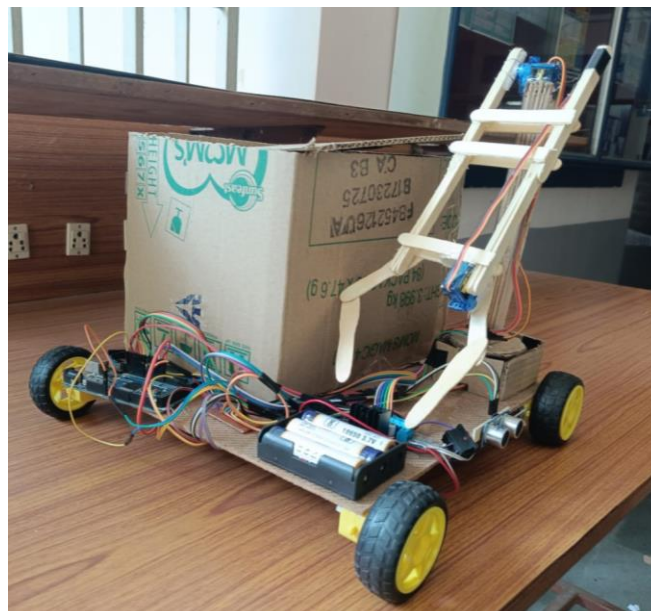


Fig-2: Serial Monitor Output Screenshot

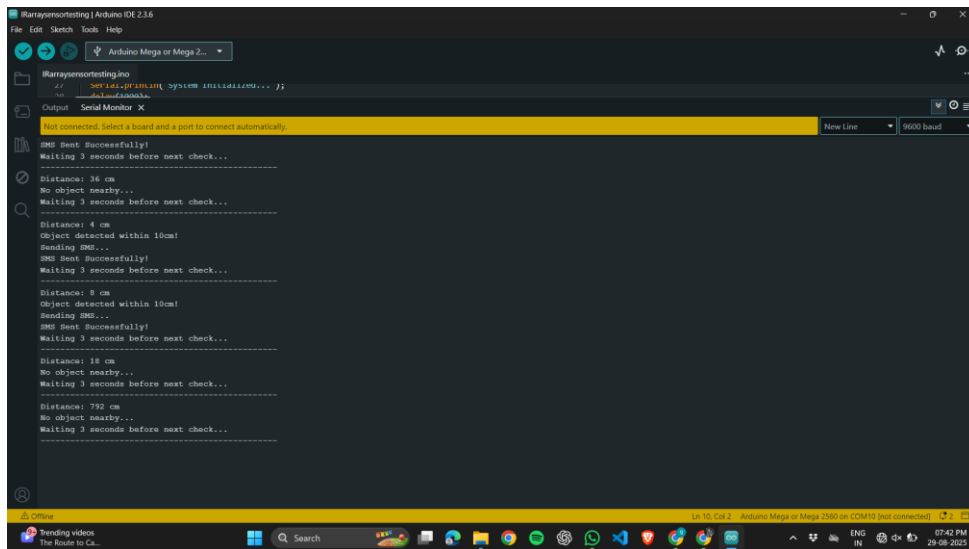
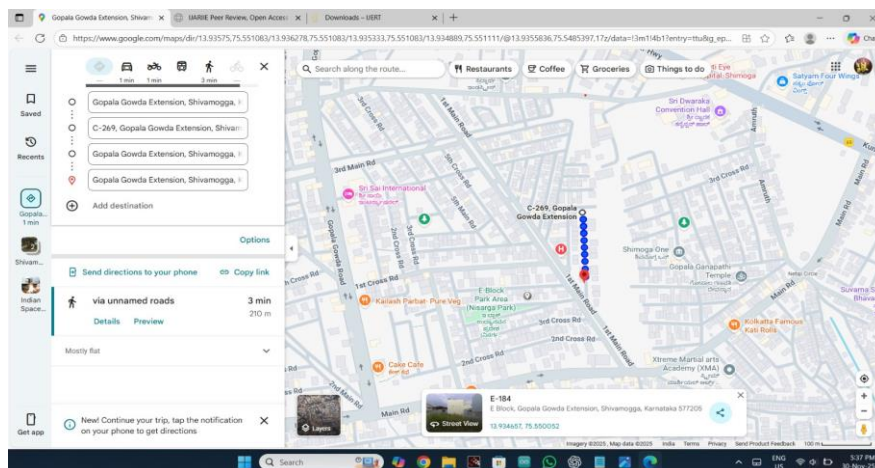


Fig-3: Image Of Garbage GPS Mapping



4. RESULTS AND DISCUSSION

The prototype demonstrated high reliability across navigation, pickup, and dumping tasks. GPS drift was minimal in open environments, and servo control proved consistent for lightweight waste. The microcontroller approach significantly improved task concurrency and responsiveness. While performance was strong, limitations were noted in low GPS signal zones and when handling heavier or irregularly shaped garbage. These results confirm that autonomous waste collection is feasible using low-cost embedded hardware.

5. FUTURE IMPROVEMENTS

- Hybrid GPS-IMU navigation using MPU6050/MPU9250
- Camera-based garbage recognition using OpenCV
- Metal-gear servos for higher payload capacity
- Cloud-based logging for performance analytics
- Multi-robot fleet coordination dashboard

6. CONCLUSION

This work successfully demonstrates the feasibility of a fully autonomous, IoT-enabled garbage collection robot integrating GPS navigation, RTC scheduling, ultrasonic sensing, and a servo-actuated robotic arm. The distributed controller architecture significantly enhances operational reliability, providing smooth coordination between navigation and object handling tasks. Experimental results show strong performance across all major modules, including accurate GPS navigation, reliable trash pickup, consistent fill-level detection, and flawless auto-dumping operation.

The system presents a scalable model for modern smart-city waste management solutions, reducing labour dependency and improving operational efficiency. The adaptability of the design allows deployment in campuses, industries, gated communities, and urban environments. The study also identifies future enhancements such as sensor fusion for improved navigation and stronger actuators for enhanced payload handling. Overall, this embedded IoT robotic system establishes a robust foundation for the next generation of smart waste collection technologies.

7. ACKNOWLEDGEMENT

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8. REFERENCES

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