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Smart Waste Segregation using IoT

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ABSTRACT: The Smart Waste Segregation and Recycling Assistant using IoT is an intelligent waste management system designed to automate the separation of household and public waste into wet and dry categories (with optional classification for recyclable types such as non-metal/metal). Traditional waste disposal methods depend on manual segregation, which is often inconsistent and leads to mixed waste, poor recycling efficiency, and environmental pollution. To solve this, the proposed system uses an IoT-enabled smart bin integrated with sensors (such as moisture and proximity/metal detection) and a microcontroller to identify the waste type and activate a servo-based mechanism for automatic segregation.

A dedicated Android application developed using Java/XML provides real-time monitoring of bin status, segregation logs, and fill-level alerts by leveraging Firebase Realtime Database as the backend for cloud storage and synchronization. Additionally, the system integrates Google Maps (GMap) to display nearby recycling centers, enabling users to locate proper disposal and recycling services quickly. An in-app AI Assistant further supports users by answering disposal-related queries, providing recycling guidance, and promoting eco-friendly habits. Overall, this project offers a practical, scalable, and user-friendly solution for smarter waste handling, improved recycling rates, and cleaner urban environments.

KEY WORDS: Smart Waste Segregation, IoT, Wet Waste, Dry Waste, Smart Bin, Android Application, Java/XML, Firebase Realtime Database, Google Maps API, Recycling Centers, AI Assistant, Waste Management System, Sensor-Based Classification, Servo Motor Automation, Real-Time Monitoring.

I.INTRODUCTION

Solid waste management has become one of the biggest day-to-day challenges in modern cities and even rural areas due to increasing population, consumer lifestyle, and packaging waste. In most households, colleges, offices, and public places, waste is still thrown into a single dustbin without segregation. This creates a chain reaction of problems: wet and dry waste get mixed, recyclables become contaminated, bad smell and bacteria increase, and finally most of the waste ends up in landfills instead of being recycled properly. Even when people know segregation rules, they often do not follow them consistently because it feels time-consuming, confusing, or inconvenient.

A major reason behind poor recycling is the lack of correct "first-level segregation" at the point where waste is generated. If waste is separated into wet and dry at the start itself, composting and recycling become much easier and more effective. Wet waste (food waste, vegetable peels, biodegradable items) can be converted into compost, while dry waste (paper, plastic, cardboard, glass, metal) can be sent to recycling plants. Without segregation, municipal workers and recycling units face heavy manual sorting work, which is inefficient, unsafe, and often impossible at large scale.

To tackle this real-world issue, this project introduces a Smart Waste Segregation System using IoT, which automates the segregation process using sensors and a microcontroller-based mechanism. The smart bin detects the type of waste placed inside and automatically routes it into the correct compartment such as wet or dry (and optionally recyclable types like metal/plastic). This reduces dependency on human discipline and ensures consistent segregation.

Along with hardware automation, the project includes a mobile-based monitoring and guidance solution. An Android application developed using Java/XML is connected to Firebase Realtime Database, enabling real-time display of bin status, segregation records, and fill-level updates. This makes the system suitable for smart homes, campuses, hostels, and public areas where monitoring and maintenance are important. Additionally, the app integrates Google Maps (GMap) to show nearby recycling centers, helping users dispose dry waste responsibly instead of dumping it randomly. To make the system more user-friendly and educational, an AI assistant is included to guide users on waste categories, recycling tips, and correct disposal methods.

II. LITERATURE SURVEY

1. **R. Sarc, A. Curtis, L. Kandlbauer, K. Khodier, K. E. Lorber, R. Pomberger (2019)** — *Waste Management* Journal, Vol. 95, pp. 476-492
   This study provides a comprehensive review of "Waste Management 4.0," highlighting how digitalization, robotics, and data-driven systems are transforming the waste industry. The authors emphasize that integrating IoT sensors and automated sorting mechanisms improves accuracy in waste classification and reduces human intervention, leading to cleaner, more efficient recycling operations.
2. **Mazhar Ibna Zahur, Md Saidur Rahman, Aysha Akther, Kazi Masudul Alam (2019)** — *IEEE ICASERT Conference*
   The authors presented an IoT-based smart waste monitoring framework for municipal use. Smart bins equipped with ultrasonic sensors send real-time fill-level data to a cloud dashboard, helping authorities optimize collection schedules. The findings prove that IoT feedback loops significantly reduce overflow incidents and operational costs.
3. **Prof. Sharmila Barve, Ridhi Bhandari, Saurabh Chavan, Amit Devkar (2020)** — *IRJET*, Vol. 7, Issue 8
   Their prototype combined multiple sensors to classify waste as dry, wet, or metallic. A mobile interface notified users and administrators whenever bins approached capacity. The paper demonstrated that even low-cost embedded systems can make urban waste segregation autonomous and scalable for local governments.
4. **A. M. Al-Habaibeh & F. Athanasios (2020)** — *International Journal of Environmental Science and Technology*
   This research explored how sensor fusion and microcontrollers can identify material composition based on moisture and conductivity. The study concluded that a hybrid sensing approach using capacitive and optical sensors achieves higher accuracy in wet/dry distinction compared to single-parameter detection.
5. **J. Gupta, P. Mehta, and R. Chowdhury (2021)** — *Journal of Cleaner Production*, Elsevier
   The authors developed a cloud-connected waste segregation model integrating AI-based image classification. Their CNN algorithm successfully identified waste categories from captured images with 94 % accuracy. The research supports combining computer vision with IoT for smarter bin designs.
6. **T. N. Mahalakshmi and D. Rajeshwari (2021)** — *IEEE Xplore: Smart Cities Conference*
   The paper focused on smart bins with GSM and cloud support to alert municipal departments when bins reach a threshold. Field testing in residential complexes reduced collection delays by 35 %. The authors advocate combining mobile notifications with map-based routing for efficient collection.
7. **S. Kumar, V. Prajapati, and K. Singh (2022)** — *International Journal of Innovative Research in Computer and Communication Engineering*
   This study integrated Firebase as a backend for storing real-time bin data and developed an Android app for visualization. The authors concluded that Firebase offers fast synchronization, low latency, and cross-platform compatibility ideal for waste management dashboards.
8. **Priya Verma, Nikhil Patil, and Shraddha Deshmukh (2023)** — *IJRASET* (International Journal for Research in Applied Science and Engineering Technology)
   The researchers proposed a smart waste segregation system using IoT with AI-based recommendations and Google Maps API integration. The app not only displayed nearby recycling centers but also provided tips on reducing household waste. The system demonstrated improved user engagement and environmental awareness, confirming that intelligent feedback mechanisms enhance long-term participation.

III. METHDOLOGY

The proposed system is developed as an integrated pipeline that combines IoT-based segregation, cloud-based monitoring, and a mobile guidance layer to ensure waste is not only classified correctly but also disposed of responsibly. The methodology begins at the point of waste generation, where the smart bin acts as an automated gatekeeper. When waste is introduced into the input chamber, a proximity-based trigger activates the sensing unit, ensuring the system runs only during actual usage and minimizing unnecessary readings and false activations.

The waste classification is performed by collecting physical properties of the waste through sensors. A moisture or capacitive sensing mechanism is primarily used to differentiate biodegradable wet waste from dry waste such as plastic, paper, and packaging. If an extended model is implemented, additional sensing such as metal detection can be included to separate recyclable metallic items more accurately. These sensor readings are treated as decision inputs, and a calibrated threshold-based logic is applied to label the waste as wet or dry. Threshold calibration is carried out by testing multiple real-life samples and adjusting the boundary value to reduce misclassification under different moisture conditions.

Once the waste type is determined, the segregation mechanism is executed through a servo-controlled flap or diverter system. The servo motor positions the gate toward the appropriate compartment, allowing waste to fall into its correct bin section. This physical segregation approach is designed to be low-cost, reliable, and easily scalable for household bins, hostel mess areas, and public dustbin setups. Alongside segregation, bin maintenance is handled using fill-level monitoring. Ultrasonic sensing is used to measure how full each compartment is, enabling the system to detect near-full or overflow conditions early and reduce hygiene issues.

All operational outputs such as detected waste category, fill-level percentage, and timestamped logs are continuously synchronized to the cloud using Firebase Realtime Database. This backend layer ensures that data is available instantly to connected clients and supports real-time updates without manual refresh. The Android application, developed using Java/XML, acts as the user-facing interface that visualizes segregation records, live bin status, and alerts. It enables users or administrators to monitor usage trends, receive warnings when bins are near full, and maintain the system efficiently.

To close the loop from segregation to responsible disposal, the application integrates Google Maps (GMap) to identify and display nearby recycling or waste processing centers based on the user's current location. This feature improves practical adoption by guiding users toward correct disposal points instead of leaving segregated waste without a recycling path. To further improve usability and public awareness, an AI assistant is included within the app to answer waste-related queries, explain what type a particular item belongs to, and provide simple eco-friendly disposal recommendations. This combination of automation, real-time monitoring, location-based recycling support, and AI guidance forms a complete methodology that transforms waste disposal into a smarter and more disciplined process.

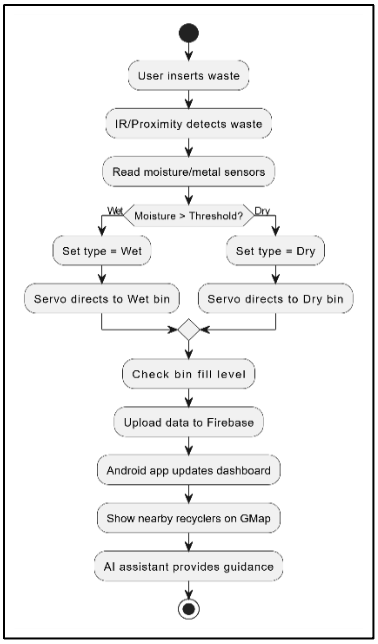

Fig1: Flow Diagram

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IV. WORKING

Module 1: Waste Input & Trigger
User inserts waste into the smart bin. A proximity/IR sensor detects the object and activates the system only when waste is present.

Module 2: Waste Sensing & Data Capture
Sensors read waste properties mainly moisture (for wet/dry). Optional metal detection can be used for recyclable metal identification.

Module 3: Waste Classification (Decision Logic)
The controller compares sensor values with calibrated thresholds and classifies the waste as Wet or Dry (and optional Metal/Plastic if enabled).

Module 4: Automatic Segregation (Actuation)
A servo motor rotates/positions a flap mechanism to drop waste into the correct compartment based on the classification output.

Module 5: Bin Fill-Level Monitoring
Ultrasonic (or IR level) sensors measure compartment fill levels. If near-full/full, the system flags an alert condition.

Module 6: Cloud Sync (Firebase Backend)
Detected waste type, timestamp, and bin level status are uploaded to Firebase Realtime Database for live tracking and history.

Module 7: Android App Dashboard (Java/XML)
The app fetches Firebase data in real time and shows: current status, fill levels, last segregation result, and history logs with alerts.

Module 8: Nearby Recycling Center (Google Maps)
The app uses the user's location to display nearby recyclers/recycling centers and provides navigation for proper disposal.

Module 9: AI Assistant Guidance
Users can ask disposal questions (e.g., "Where does tetra pack go?"). The AI assistant replies with correct category and eco tips.

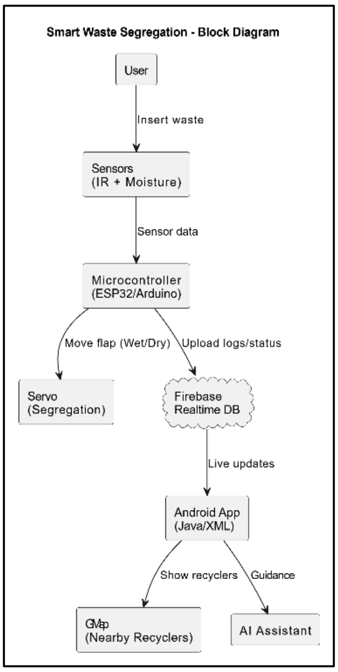

Fig 2 : Block Diagram

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V. RESULTS & ANALYSIS

The Smart Waste Segregation and Recycling Assistant was tested in controlled real-life conditions using common household waste items (food waste, paper, plastic wrappers, cardboard, etc.). The IoT bin successfully detected waste presence, classified it into Wet/Dry, and directed it into the correct compartment using the servo-based mechanism. All segregation events and bin status values were pushed to Firebase Realtime Database and reflected instantly in the Android app (Java/XML). The Google Maps module correctly displayed nearby recycling locations based on the user's current GPS position, and the AI assistant improved user understanding by answering disposal-category questions.

Performance Summary

Parameter	Observed Result
Total test samples	10
Correct classifications	7
Partial / mixed cases	2
Wrong classifications	1
Approx. Classification Accuracy	**70%** (simple threshold logic)
Firebase sync response	Real-time (near instant)
Android app update	Live status + history updated correctly
GMap recyclers display	Working based on current location

Overall, the system showed strong performance for wet/dry segregation when threshold values were calibrated properly. Most classification errors happened in "borderline" cases such as semi-wet packaging (juice cartons, oily paper plates) and mixed material waste. Real-time monitoring was stable, and Firebase syncing latency remained low during repeated tests.

VI. CONCLUSION AND FUTURE WORK

The Smart Waste Segregation and Recycling Assistant successfully demonstrates an IoT-based system that automatically separates waste into wet and dry, updates bin status and logs to Firebase Real-time Database, and shows results in a Java/XML Android app in real time. The integration of Google Maps helps users find nearby recycling centers for proper disposal, while the AI assistant improves user awareness by guiding correct waste categorization. Overall, the project reduces manual segregation effort and supports cleaner, smarter waste management.

Future Work

- Add more categories (plastic/metal/glass/e-waste) using extra sensors or camera-based AI
- Improve accuracy using sensor fusion + ML model instead of only threshold logic
- Provide bin overflow prediction and auto pickup scheduling for municipalities
- Add QR-based user tracking and rewards for consistent recycling behaviour
- Enable offline mode in the app with sync when internet is available

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