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ECOBIN: Automated Waste Segregation for a Sustainable Future

Dr. B. Kalpana¹, K. Arjun², S. Pradosh³, M. Tinesh Pandian⁴, V.I Vipin Kanna⁵

Associate Professor, Department of Information Technology, R.M.D. Engineering College, Chennai,
Tamil Nadu, India¹

U. G. Student, Department of Information Technology, R.M.D. Engineering College, Chennai, Tamil Nadu, India^{2,3,4,5}

ABSTRACT: India faces a massive waste disposal problem, producing around 62 million tons of waste each year, most of which is dumped at landfills, leading to resource loss and devastating the environment. Existing waste management infrastructure struggles with inefficient sorting, limited recycling education, and improper waste disposal. This paper proposes a novel IoT-enabled Waste Sorting and Recycling Classification Detection System to classify initial sorting whether categories biodegradable, non-biodegradable, and e-waste and object classification using YOLOv8 deep learning model. Users receive AI-powered recycling recommendations to create sustainable practices and limit the generation of waste. An additional IoT-integrated dashboard tracks waste categories and carbon footprint savings, visualizing the system's impact on waste reduction. Promising initial results show that things can be sorted more accurately and more effectively recycled, opening doors to scalable, lower impact waste management strategies.

KEYWORDS: Segregation, motor, IR sensor, Metal detector, Moisture sensor, Embedded system, Sensor, Arduino, Waste Management, Servo Motor.

I. INTRODUCTION

Waste management is a growing challenge in urban and rural areas due to the increasing generation of solid waste, bio-waste, and electronic waste (e-waste). Improper segregation of waste leads to environmental pollution, inefficient recycling, and health hazards. Traditional waste disposal methods are labor-intensive and often ineffective, resulting in significant landfill accumulation and resource wastage. By integrating Internet of Things, smart sensors can detect waste types based on material properties such as conductivity, weight, and infrared reflection. The system then directs the waste to appropriate bins, reducing human effort and increasing efficiency. Real-time data collection and monitoring through cloud-based platforms enable better waste tracking and management, contributing to a cleaner and more sustainable environment. This paper explores the development and implementation of an IoT-based waste segregation system, highlighting its advantages in reducing landfill waste, promoting recycling, and improving overall waste management efficiency.

II. LITERATURE SURVEY

[1] Several studies have proposed sensor-based waste segregation systems to distinguish between different types of solid waste. For example, research by [Author et al., Year] developed a smart bin equipped with capacitive, inductive, and infrared sensors to identify materials such as plastic, metal, and glass. The system successfully categorized waste based on its physical and electrical properties. Another approach, proposed by utilized machine learning models to improve the accuracy of solid waste classification. Using image processing techniques and artificial intelligence, their system achieved a higher recognition rate in sorting recyclables and non-recyclables.

[2] Bio-waste, primarily consisting of organic matter such as food scraps and agricultural residues, requires effective segregation for composting or biogas production. Studies like [Author et al., Year] introduced moisture and gas sensors to differentiate between organic and inorganic waste. The system automatically directed biodegradable waste for composting, reducing landfill accumulation. Furthermore, IoT-enabled composting bins have been explored to monitor temperature, humidity, and decomposition progress in real-time. Researchers demonstrated that integrating IoT with waste management enhances process optimization and reduces greenhouse gas emissions.

[3] Electronic waste (e-waste) contains hazardous materials that require specialized handling. A study by [Author et al., Year] implemented a RFID and QR code-based tracking system for e-waste segregation. This approach improved the identification and recycling process by directing components to proper disposal centers. Additionally, research has examined AI-powered waste classification using deep learning and computer vision. By analyzing discarded electronic items through image recognition, the system efficiently categorized different types of e-waste for recycling.

[4] IoT has played a crucial role in real-time waste monitoring and collection optimization. Studies like [Author et al., Year] proposed smart bins with cloud-based data storage for tracking waste levels and optimizing collection routes. This method significantly reduced operational costs for municipalities while ensuring timely waste disposal.

[5] Moisture and gas sensors detect biodegradable materials based on decomposition gases like methane and CO₂. Color and texture sensors classify organic waste, helping in composting or biogas production. Temperature and humidity sensors monitor composting conditions and adjust aeration automatically. IoT-powered smart composting bins provide real-time data on organic waste decomposition. Automated biogas plants integrated with IoT collect organic waste and convert it into renewable energy.

[6] Smart bins connected to cloud platforms collect real-time data on waste levels. AI-powered route optimization for garbage trucks reduces fuel consumption and improves waste collection efficiency. Blockchain technology is being explored for secure waste tracking and recycling transactions. IoT-enabled e-waste disposal apps assist users in locating authorized recycling centers.

[7] AI-powered classification sorts electronic components into reusable and hazardous categories. IoT-based smart bins for e-waste notify collection centers when bins are full, ensuring proper disposal. GIS (Geographic Information Systems) integrated with IoT track waste generation patterns in urban areas. Mobile apps for citizens enable reporting of waste overflow issues and request faster collection. IoT-based air pollution monitoring systems analyze waste decomposition effects on air quality.

[8] Studies says that have implemented inductive, capacitive, and infrared sensors to distinguish between metals, plastics, and biodegradable waste. Other researchers have used ultrasonic sensors to detect waste levels in bins, optimizing collection schedules and reducing overflow issues. Research explored computer vision and deep learning models to classify solid waste using image recognition. AI-powered robotic arms have also been developed to automatically sort recyclables from non-recyclables, improving segregation efficiency.

[9] Studies shows utilized moisture, gas, and pH sensors to detect biodegradable waste and separate it from non-biodegradable materials. Researchers have developed automated composting units that use IoT sensors to monitor decomposition conditions such as temperature and humidity, ensuring optimal composting processes. Smart biogas plants have also been explored, converting bio-waste into renewable energy through IoT-enabled monitoring systems.

[10] E-waste contains hazardous materials like lead, mercury, and cadmium, requiring specialized disposal methods. IoT solutions have been explored to improve e-waste segregation, tracking, and recycling. RFID and Smart Tracking Systems implemented RFID tags and QR codes to track electronic devices and direct them to appropriate recycling centers. AI-Powered E-Waste Sorting: Studies have integrated computer vision and X-ray fluorescence sensors to identify valuable materials such as gold and copper in discarded electronics, optimizing resource recovery.

[11] The integration of Internet of Things (IoT) technology in waste segregation has gained significant attention in recent years. IoT-enabled waste segregation systems utilize sensors, artificial intelligence (AI), machine learning (ML), and cloud computing to automate waste classification, improve recycling efficiency, and reduce environmental pollution. This literature survey explores existing research on IoT-based waste segregation methods, challenges, and future directions.

[12] IoT-based waste segregation has significantly improved waste sorting, recycling, and disposal efficiency. Advanced sensor technology, AI, and cloud-based monitoring have enhanced the effectiveness of waste management in smart cities. However, future research must focus on cost-effectiveness, large-scale implementation, and sustainability to make smart waste segregation a global reality. This literature survey highlights the transformative role of IoT in

waste segregation. Future research should explore scalable, cost-effective solutions that integrate AI, blockchain, and IoT for better waste management and environmental sustainability.

III. COMPONENTS USED

A. ARDUINO UNO:

The main microcontroller in the system is the Arduino Uno, which has six analog inputs and fourteen digital I/O pins. It oversees system operations, processes sensor inputs, and initiates the proper actions. It is appropriate for real-time monitoring and communication chores that are crucial to the project because of its dependability and simplicity.

B. STEPPER MOTOR AND DRIVER:

A motor driver that is designed to drive the motor like a stepper motor to rotate continuously by controlling the exact position without using a feedback system is known as a stepper motor driver. The drivers of this motor mainly provide variable current control as well as several step resolutions.

C. PROXIMITY SWITCH (NPN):

Proximity sensors are used to detect objects without making physical contact. There are 2-wire and 3-wire proximity sensors, and 3-wire proximity sensors are more popular. There are two main types of proximity sensors based on their output type: NPN and PNP. selecting the correct type of proximity sensor for a particular application can ensure the correct operation of a system. This article aims to provide an outline of the two main output types and a guide on how to connect a proximity sensor to a PLC.

D. SERVO MOTOR:

A servomotor is a closed loop servomechanism that uses position feedback (either linear or rotational position) to control its motion and final position. The input to its control is a signal (either analog or digital) representing the desired position of the output shaft.

E. RAIN DETECTOR SENSOR:

A rain detector sensor or rain switch is a switching device activated by rainfall. There are two main applications for rain sensors. The first is a water conservation device connected to an automatic irrigation system that causes the system to shut down in the event of rainfall. The second is a device used to protect the interior of an automobile from rain and to support the automatic mode of windscreen wipers.

F. 18650 BATTERIES AND HOLDER:

An 18650 battery or 1865 cell is a cylindrical lithium-ion battery common in electronic devices. The batteries measure 18 mm (0.71 in) in diameter by 65 mm (2.56 in) in length, giving them the name 18650. The battery comes in many nominal voltages depending on the specific chemistry used.

G. IR SENSOR:

IR sensor is an electronic device, that emits the light in order to sense some object of the surroundings. An IR sensor can measure the heat of an object as well as detects the motion. Usually, in the infrared spectrum, all the objects radiate some form of thermal radiation. These types of radiations are invisible to our eyes, but infrared sensor can detect these radiations.

H. 5V BUZZER:

An audio signaling device like a beeper or buzzer may be electromechanical or piezoelectric or mechanical type. Generally, it is powered through DC voltage and used in timers, alarm devices, printers, alarms, computers, etc.

I. YOLOv8:

In the world of computer vision, YOLOv8 object detection really stands out for its super accuracy and speed. It's the latest version of the YOLO series, and it's known for being able to detect objects in real-time. YOLOv8 takes web applications, APIs, and image analysis to the next level with its top-notch object detection.

IV. WORKING

The working of the complete smart waste control system is based on sensors, the response from the sensors make the work of servomotor which directs the waste materials in a particular direction. Initially the waste that is placed on the primary plate there the wet and the dry waste will get separated. There we place a moisture sensor and a normal proximity sensor that detect presence of an object. Here how we are going to separate is taking response from both the sensors. If both the sensors give output value high that means it is a wet waste and the servo motor will rotate to 45 degrees in clockwise direction. In another case only the proximity sensors will get high value that means it is a dry waste and the motor will go to angle 315 in clockwise direction. By that way wet and dry waste will get separated. Now we have to separate metal and non-metals from dry waste for this have to an proximity sensor and Inductive proximity sensor which detect only metal objects. The separated dry waste got placed on plate 2 here the metallic sensor and proximity sensor readings will be taken and based on that response the plate using servo motor will be the sensors give high value that will be consider as metal the motor will rotate 45 degrees in anti-clock wise direction. If only proximity sensor got high value then it will be non-metal. The foremost goal of this project is to automatically segregate the wastes and to perceive the level of the dustbins which is delivered through wireless mesh network. With such information, litter bin providers and cleaning contractors are able to make better decision for the efficient disposal. IR sensor identifies the objects, Moisture and metal sensors detects the wet and metal waste. Ultrasonic sensor observes the levels of bin.

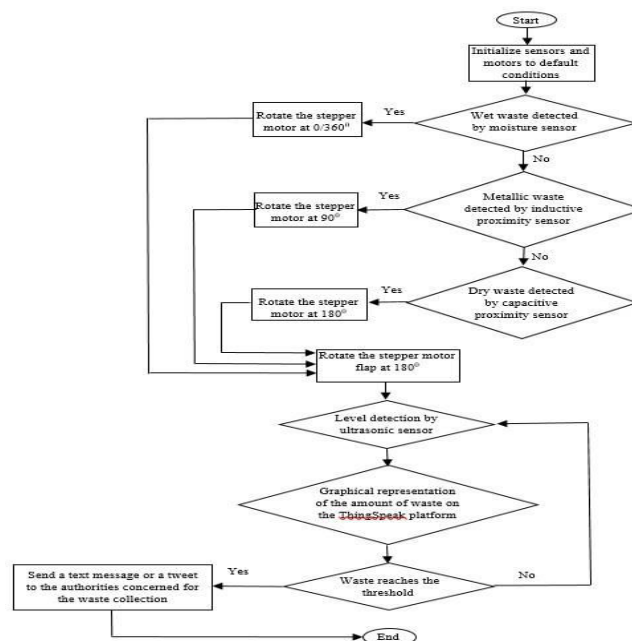


Fig. 1. Flowchart

The process begins with initializing sensors and motors to their default conditions. When waste is deposited, a moisture sensor first checks whether it is wet waste. If detected, the system rotates a stepper motor by 360° to direct the waste into the designated bin. If not, an inductive proximity sensor determines if the waste is metallic and, if confirmed, rotates the stepper motor 90° to dispose of it accordingly. If the waste is neither wet nor metallic, a capacitive proximity sensor checks for dry waste and rotates the stepper motor 180° for proper disposal. After classification, a stepper motor flap rotates 180° to guide the waste into the correct bin. Additionally, an ultrasonic sensor continuously monitors the waste level in the bin and transmits the data to the platform for graphical representation.

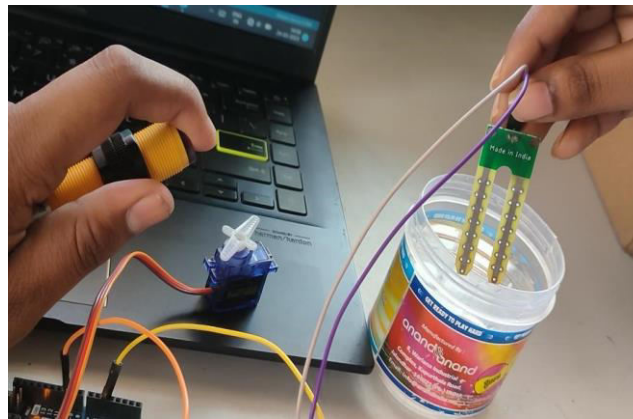


Fig. 2. Servo motor in dry condition

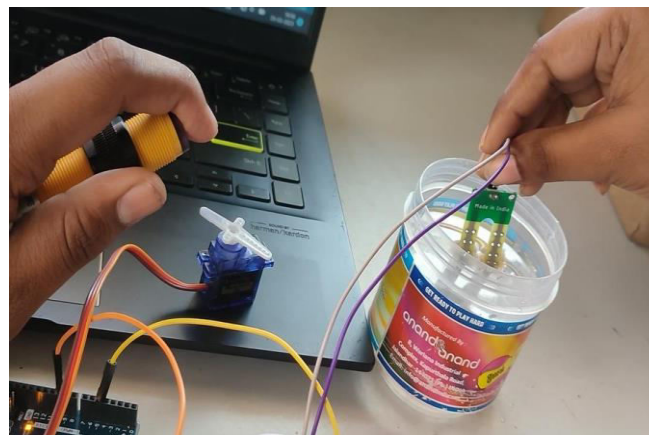


Fig. 3. Servo motor in wet condition

V. RESULTS

1. WET WASTE:

The smart bin was experimental with various items which are disposed on a regular bases. The wastes such as vegetable peels, wet tissue, where used to test the effectiveness of segregation of wet waste, it was observed that the system started to function only offer the waste is placed on the upper bin, following a three second delay period, the materials thrown by the user was correctly segregated into its respective wet waste sub bin. Wet waste includes organic and bio-degradable materials that decompose naturally over time. It mainly consists of food waste, vegetable peels, fruit scraps,

garden waste, and leftover cooked food. Contains high moisture content. It decomposes quickly under natural conditions. It can be composted to produce organic fertilizer.

Wet waste, also known as organic waste, consists of biodegradable materials such as food scraps, vegetable and fruit peels, leftover cooked food, tea leaves, coffee grounds, and garden waste like leaves and flowers. This type of waste decomposes naturally and can be converted into compost or biogas, making it an environmentally friendly resource when managed properly. Proper segregation of wet waste from dry waste is essential for effective waste management, as it helps reduce landfill burden and promotes sustainable practices. Composting wet waste not only reduces pollution but also enriches the soil with essential nutrients, supporting plant growth and agricultural productivity. By adopting responsible disposal methods, individuals and communities can contribute to a cleaner and healthier environment.

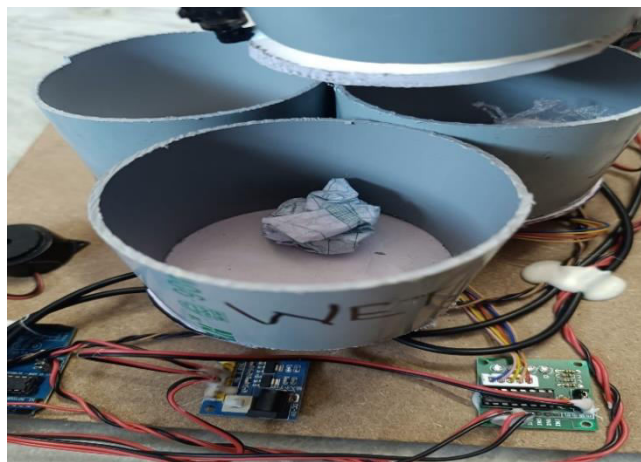


Fig. 4.1. Wet waste

2. DRY WASTE:

Similarly the dry waste segregation test condition was experimented by using paper, foil, wrapper. It was observed that the functioning started only after the trash items was placed on the upper bin. Followed by the second delay period, The trash items was correctly segregated into its respective dry waste sub bin. Plastic waste consists of synthetic polymer-based materials such as plastic bags, bottles, containers, and packaging materials. These are non-biodegradable and pose severe environmental threats. Plastic waste is a major environmental issue that threatens ecosystems, wildlife, and human health. Every year, millions of tons of plastic are produced, with a significant portion ending up in landfills, oceans, and natural habitats. Since plastic takes hundreds of years to decompose, it accumulates and pollutes the environment, harming marine and terrestrial life.



Fig. 4.2. Dry waste

3. METAL WASTE:

The metal waste segregation is experimented by using the key, ring and coin. It was observed that the functioning started only after the garbage items was placed on the upper bin, followed by the three second delay period, the trash items was correctly segregated into its respected metal waste sub bin. Metal waste includes discarded metal objects like aluminum cans, iron scraps, copper wires, and electronic waste (e-waste) containing metals.

Metal waste consists of discarded metal materials such as aluminum cans, iron scraps, copper wires, steel products, and old appliances. Unlike organic waste, metal waste is non-biodegradable but highly recyclable, making it a valuable resource for sustainable waste management. Recycling metal reduces the need for mining raw materials, conserving natural resources and reducing environmental pollution. Proper segregation of metal waste ensures that reusable metals are processed efficiently, minimizing energy consumption and greenhouse gas emissions.



Fig. 4.3. Metal waste

VI. DISCUSSION

The implementation of solid-waste, bio-waste and e-waste segregators using IoT, AI, and sensor-based automation has revolutionized waste management by making segregation more efficient and systematic. Traditional waste disposal methods often rely on manual sorting, which is not only labor-intensive but also prone to errors, leading to ineffective recycling and increased landfill accumulation. With the integration of machine learning, image processing, and real-time monitoring, smart waste segregation systems can automatically identify and sort waste into categories such as bio-waste, plastic waste, and metal waste, ensuring that each type is processed appropriately. This reduces contamination between waste types and enhances the efficiency of recycling and waste treatment facilities. Another key discussion point is the role of automation and robotics in waste management. While current systems primarily use proximity sensors, infrared sensors, and servo motors for sorting, future advancements could involve AI-powered robotic arms capable of handling complex waste segregation tasks with minimal human intervention. Moreover, IoT-based data analytics and cloud computing can provide valuable insights into waste generation trends, allowing cities to optimize waste collection schedules, reduce operational costs, and minimize environmental impact.

VII. CONCLUSION

The implementation of solid-waste, bio-waste and e-waste segregators using IoT, AI, and sensor-based automation is a significant step toward efficient and sustainable waste management. Proper segregation of waste at the source plays a crucial role in reducing environmental pollution, improving recycling processes, and minimizing landfill waste. By integrating advanced technologies such as machine learning, robotics, and cloud-based monitoring, smart waste management systems can become more efficient, reducing human intervention while increasing accuracy in sorting different waste types. Moreover, the use of renewable energy sources, blockchain for transparent tracking, and IoT-driven real-time monitoring can further optimize waste collection and disposal. Although challenges such as cost, scalability, and

public participation remain, future innovations in affordable solutions, automation, and smart city integration can help overcome these barriers. With continuous advancements and proper implementation, smart waste segregators can contribute significantly to a cleaner environment, improved recycling efficiency, and a sustainable circular economy, ensuring a greener and healthier future for upcoming generations. The ability to automate waste identification, sorting, and disposal not only enhances efficiency but also promotes cleaner and more sustainable urban environments. Furthermore, the incorporation of real-time monitoring, cloud-based analytics, and robotic automation enables municipalities and waste management authorities to optimize waste collection schedules, reduce operational costs, and improve overall waste-handling efficiency.

In conclusion, a Smart Waste Management System is a revolutionary approach to handling waste efficiently and sustainably. By leveraging technologies like IoT, sensors, data analytics, and automated collection systems, it enhances waste segregation, reduces operational costs, and minimizes environmental pollution. Smart waste management promotes recycling, optimizes waste collection routes, and prevents overflow, contributing to cleaner cities and healthier communities. Implementing such systems not only conserves resources but also supports the global effort toward sustainable development. As urbanization continues to grow, adopting smart waste management solutions becomes essential for creating a cleaner, greener, and more efficient future.

VIII. FUTURE WORKS

The Automatic Waste Segregator has been implemented for the segregation of waste into dry, wet and metallic waste. Smart dustbin is an innovative step in the direction of bringing a change in the current garbage disposal system. Further the self-changing technology can be implemented so that the battery of the smart bin is low on power then using solar tracker the smartbin. The advancement of smart waste segregators has transformed waste management by integrating IoT, AI, and sensor-based automation. However, there is still significant scope for improvement in terms of efficiency, accuracy, and cost-effectiveness. Future developments can focus on AI and machine learning models that enhance waste classification using deep learning and computer vision. These technologies can improve the system's ability to distinguish between different waste types, including complex materials like multi-layered plastics and mixed waste. Additionally, advanced sensor technology, such as spectroscopy-based sensors and hyperspectral imaging, can enhance the detection of various materials with higher precision, enabling better segregation of bio-waste, plastics, and metals. Another critical area of improvement is the integration of IoT and cloud-based waste monitoring. Future systems can use real-time data analytics to optimize waste collection by sending alerts when bins are full, reducing operational costs and improving efficiency. Automated robotic sorting mechanisms, including robotic arms and conveyor belt systems, can further enhance waste separation by reducing human intervention and increasing processing speed. Additionally, blockchain technology can be implemented to create a transparent and tamper-proof waste management system, ensuring proper tracking of recyclable and hazardous waste.

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