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Design And Implementation of a GSM-Enabled Smart Dustbin for Automated Biodegradable and Non-Biodegradable Waste Segregation

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Abstract: The rapid urbanization has contributed to a high level of generation of municipal solid waste and therefore, efficient waste segregation is necessary. In this paper, a low cost GSM enabled smart dustbin is designed and implemented in automated separation of biodegradable and non- biodegradable waste using embedded system technology. The suggested system employs the method of an ultrasonic sensor to detect the waste and a moisture sensor to classify the waste according to the preset threshold values. The sensor data is processed on an Arduino Uno microcontroller and a servo motor that directs the waste into the correct compartments. GSM module comes with real time SMS notifications to monitor remotely even without the internet. The classification accuracy and response time of 80.55 percent and an average response time of 1.5 seconds were attained with the use of 36 waste samples through experimental evaluation. The proposed system is a reliable and less expensive solution in small-scale smart waste management application.

Keywords - *Embedded systems, Automated waste segregation, Moisture-Based Classification, GSM Communication, Sensor-Based Smart Dustbin, Arduino Uno, Solid Waste Management, Smart City Applications.*

INTRODUCTION

The rapid urbanization and population growth has greatly contributed to the generation of the municipal solid waste. Poor separation of waste on the source level lowers the efficacy on the recycling process and leads to pollution of the environment, overflow of landfills and human health hazards. Waste management involves ensuring that biodegradable and non-biodegradable materials are classified at the initial stages so that the process of recycling is enhanced and the environment is not greatly affected.

Manual sorting of waste is the major mode of traditional waste sorting which is labor intensive, time consuming, and unhygienic. Automated waste management systems have been suggested in recent years based on sensor-based detection, Internet of Things (IoT) platforms and artificial intelligence (AI) based image processing methods. Although AI-based systems are highly accurate in their classification, they need cameras, high computing capabilities and high cost. IoT-based systems can be implemented to monitor in real-time, but require constant internet connectivity and cloud infrastructure.

This paper aims to overcome such limitations by proposing a low-cost embedded system-based smart dustbin that will be able to automatically divide the biodegradable and non-biodegradable garbage based on the moisture level. The system employs the use of ultrasonic sensor to detect objects and moisture sensor to categorize the waste according to predetermined threshold values. The sensor inputs are processed by the Arduino Uno microcontroller which in turn drives a servo motor to sort waste into the correct compartment. Also it has a GSM module which gives an SMS notification of bin status in real time without the need of internet connection.

The system proposed is aimed at affordability and at simplicity and simplicity in deploying it in small scale setups like households, learning institutions, and offices. Experimental validation was conducted to test the classification accuracy and response time to prove the practicality of the system.

The rest of the paper will be structured in the following way: Section II will provide the problem statement, Section III will discuss the related works, Section IV will elaborate on the system methodology, Section V will discuss experimental results and analysis, and the concluding section of the paper will be Section VI of the paper which will uphold the future scope.

The proposed system has several capabilities unlike most IoT-based smart dustbin systems that need constant internet connectivity and cloud infrastructure to process the data, thus does the autonomous waste classification based on the moisture-based detection and delivers the GSM-based SMS alerts.

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I. LITERATURE REVIEW

Rapid urbanization of the population has greatly contributed to the waste generation of the municipality posing a great challenge to the sustainable waste management. To counter this, a number of researchers have recommended smart dustbin systems that integrate embedded systems, sensor based systems and automatic monitoring technologies.

Sudha et al. [1] offered a smart dustbin monitoring device with an Arduino Uno and ultrasonic sensors to automatize the process of opening and closing the lid and monitor the amount of garbage in the dustbin. The ultrasonic sensor measures the distance of the waste surface to the sensor, to estimate bin capacity. Despite the fact that the system enhances the hygiene and less manual contact with the waste, it majorities on monitoring and lid automation without an automated waste classification system.

Shreeshayana et al. [2] suggested a system of dry and wet waste sorting and production of compost as an automated one. Not only did their model separate waste but also biodegradable waste was processed into compost and this allowed sustainable waste management. Nevertheless, composting units added complexity and space to the systems as well as raising the cost of implementation.

Shubha et al. [3] came up with a multi-sensor smart dustbin that has ultrasonic, metal detectors and odor sensors to enhance classification of waste. The combination of various sensing mechanisms further increased the accuracy of segregation by determining the various material properties. The increase in the number of sensors, however, raised the complexity of hardware, energy requirements, and the general price of the system.

Kirthana et al. [4] and Agarwal et al. [5] suggested Arduino-based smart dustbin systems, which are cost-effective, to automate the dry and wet waste segregation. They used sensor-detected and servo-controlled systems to sort waste to the right compartments. Nevertheless, both research papers included a small scale of experimental validation, as well as, lacking detailed performance appraisal like an accuracy analysis or large scale experimentation. Orunsolu et al. [6] used a Bluetooth-based smart dustbin to monitor the waste in the office, although the distance of communication was limited. The model of segregation based on conveyors was proposed by Sony et al. [7] and added mechanical complexity.

Muneeswaran et al. [8] designed an embedded system of waste segregation and monitoring, whereas Shahararil and Po'ad [9] added gas and load sensors to the detection system to achieve better detecting capacity. Ramya et al. [10] concentrated on smart city waste collection technologies based on monitoring on Arduino.

Intelligent smart trash bin architecture is another set of smart city applications as suggested by Mohamed et al. [11] through sensor integration and automated monitoring. Their system was geared towards massive implementation but complex sensing infrastructure was necessary.

Zubair et al. [12] came up with a hybrid AI and mechanical-based system on waste segregation to enhance the accuracy of classification. Despite its effectiveness, the application of AI had the negative effect of increasing the hardware cost and complexity of the computations.

Yogalaksmi et al. [13] introduced an IoT-based automatic waste segregation and monitoring system, having the cloud connectivity to analyze the data in real-time. Nonetheless, the system relied on the Internet infrastructure that was stable.

Borojeni and Abdi [14] suggested a smart waste management system based on IoT WMS which incorporated several sensors and real- time features on monitoring and transmitting the data. The system focuses on urban implementation that is scalable and centralized waste management, based on the IoT infrastructure. Whereas the method enhances the efficiency of monitoring, it relies on network connectivity and cloud based processing that makes the implementation more complex than embedded standalone systems.

II. RESEARCH GAP

The current smart garbage management systems are mainly related to the monitoring of the level of garbage or are based on the complicated multi-sensor and IoT-based infrastructure. IoT-enabled systems enhance central monitoring and scalability, but require constant internet connectivity and cloud infrastructure which make them more expensive to implement and complex to use. Multi- sensor and artificial intelligence-based methods improve the accuracy of classification, but need to add hardware and increase computing capabilities. Hence, a cheap, and easy-to-use embedded waste segregation system that can achieve biodegradable and non-biodegradable segregation and real- time notification, without the use of international connection networks will be a sensible need particularly in small scale and rural implementation scenarios.

Table I: Comparison of Existing Smart Waste Segregation Systems

Ref.	Approach	Sensors Used	Key Limitation
[1]	Smart dustbin monitoring	Ultrasonic	Only level detection
[2]	Auto segregation + compost	Moisture	No real-time monitoring
[3]	Multi-sensor smart dustbin	Ultrasonic, Metal, Odor	High hardware complexity
[4]	Dry/Wet segregation	Ultrasonic, Servo	No accuracy validation
[5]	Lid automation system	Ultrasonic	Focused on lid only
[6]	Office smart dustbin	Ultrasonic, odor	Short range communication
[7]	Conveyor segregation	Mechanical + Arduino	High cost & complexity
[8]	Embedded monitoring	Basic Sensors	No performance metrics
[9]	Gas + load detection	Ultrasonic, IR, Gas, Load cell	Increased system complexity
[10]	Smart city collection	Metal detection	High infrastructure cost

III. PROBLEM STATEMENT

Although a variety of systems of smart dustbins have been developed, there are still a number of limitations in the practical application. Most of the current systems are concerned with garbage level measurements and not measuring the actual wastes. Multi-sensor based systems enhance the ability to do classification but also add complexity to the hardware and cost of implementation.

IoT-based systems need constant access to the internet and cloud computing, which do not allow small-scale and rural applications. The methods of waste classification based on AI are highly accurate but require camera modules, high computing capability, and more power.

Moreover, not all the current studies are experimentally validated, analyzed concerning accuracy and evaluated as to the performance of the statistics.

Thus, an inexpensive embedded waste segregation system is required that:

- Automatically classifies biodegradable and non-biodegradable waste
- Provides real-time notification without internet dependency
- Maintains low hardware complexity
- Includes experimental validation and performance analysis

The proposed system aims to address these limitations through moisture-based classification integrated with GSM- enabled monitoring.

IV. CONTRIBUTIONS OF THE PROPOSED SYSTEM

The primary contributions of this work are summarized as follows:

- Development of a low-cost GSM-enabled smart dustbin for automated biodegradable and non- biodegradable waste segregation.
- Implementation of moisture-based classification using predefined threshold values.
- Integration of real-time SMS notification without internet dependency.
- Experimental validation with accuracy and response- time analysis.
- Simplified hardware architecture suitable for small- scale deployment.

V. PROPOSED SYSTEM

A. System Overview

The offered system is a GSM-powered smart dustbin that will be used to separate biodegradable and non-biodegradable garbage automatically with the help of a moisture-based classification system. The system comprises of a sensing, processing, actuation, display, and communication module that is combined using an Arduino Uno microcontroller.

The architecture is created to ensure low cost, less hardware complexity and real-time notification without depending on the internet.

B. BLOCK DIAGRAM DESCRIPTION

The overall system architecture consists of the following functional blocks:

- Ultrasonic Sensor – Waste Detection
- Moisture Sensor – Moisture Level Detection
- Arduino Uno – Central Processing Unit
- Servo Motor – Waste Direction Control
- 16×2 LCD Display – System Status Display
- GSM Module SIM800L – SMS Notification
- Power Supply Unit – Regulated DC Supply

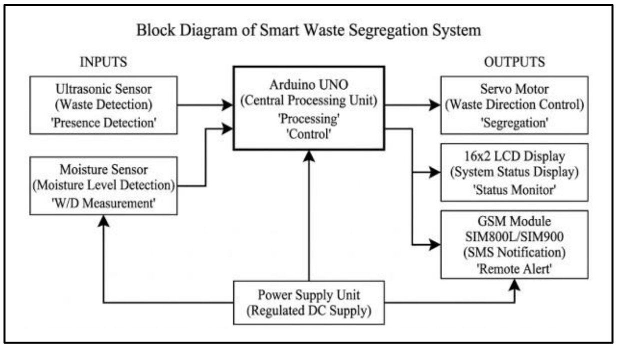

Fig.1 Block Diagram

C. SYSTEM WORKING PROCEDURE

1. The ultrasonic sensor reacts to the object within a defined distance threshold when the waste is put near the bin.
2. The moisture sensor is enabled by the Arduino to detect the amount of moisture in the waste.
3. The predetermined threshold value is compared to the measured analog value:
   • When moisture value exceeds threshold, then Biodegradable waste.
   • On the condition of moisture value being less than the threshold, Non-biodegradable waste. According to the result of the given classification, the servo motor will be connected to the rotational movement that will guide the waste to the compartment it is supposed to enter.

4. The LCD screen presents the particular wastage detected.
5. The GSM module is used to transmit an SMS alert on the type of waste or bin status through AT command protocol.
6. The system goes back to the original position where it starts working the next time..

Working Flow:

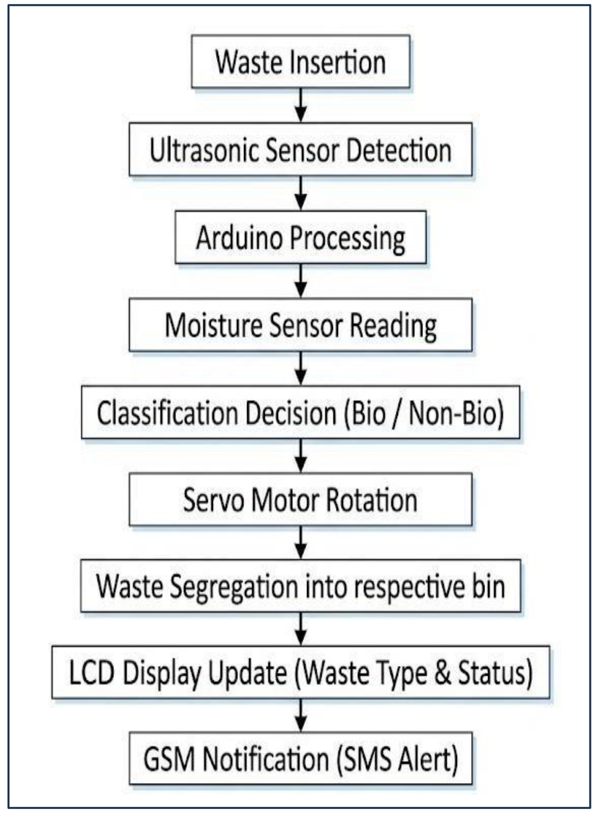

Fig.2 Working Flow

D. COMMUNICATION PROTOCOL

The module used at the GSM side to communicate with the Arduino is the GSM module (SIM800L), which interacts with the Arduino through serial communication. The SMS mode and transmit notifications are configured using AT commands. Example commands:

AT+CMGF=1 (sets SMS mode) AT+CMGS="+91xxxxxxxx"

This ensures real-time notification without requiring internet connectivity.

E. PROPOSED SYSTEM ADVANTAGES

- Low-cost embedded implementation.
- Does not require internet connectivity.
- Simple threshold-based classification.
- Real-time SMS notification.
- Suitable for small-scale deployment.

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F. ARCHITECTURE DIAGRAM

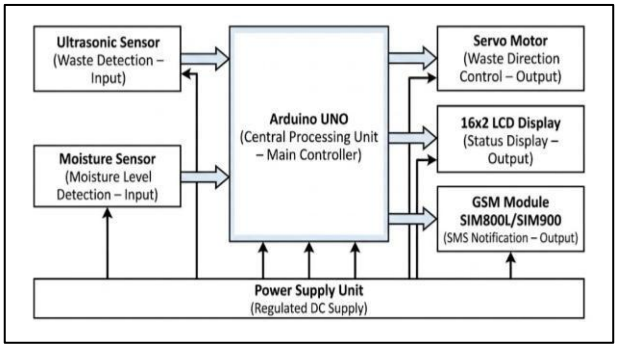

Fig.3 Architecture Diagram

1. Layered Architecture Description:

i. Sensing Layer

• Ultrasonic sensor detects object presence

• Moisture sensor measures analog moisture value

ii. Processing Layer

• Arduino Uno performs:

• Threshold comparison

• Decision making

• Actuator control

• Serial communication

iii. Actuation Layer

• Servo motor rotates 0° or 90° based on classification

iv. Display Layer

• 16×2 LCD shows:

• "Biodegradable Waste Detected"

• "Non-Biodegradable Waste Detected"

• "Bin Full"

v. Communication Layer

• GSM module sends SMS alerts using AT command protocol

• No internet dependency

2. System Flowchart:

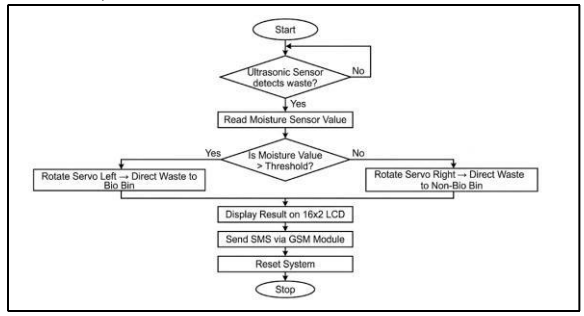

Fig.4 Flowchart

A. Flowchart Explanation:

The system starts by initializing the Arduino Uno, sensors, LCD, servo motor, and GSM module.

The ultrasonic sensor continuously checks for the presence of waste.

When an object is detected within the threshold distance, the moisture sensor measures the moisture level of the waste.

The Arduino compares the measured value with a predefined threshold:

• If the moisture value is greater than the threshold, the waste is classified as biodegradable.

• Otherwise, it is classified as non-biodegradable.

Based on the decision, the servo motor rotates to direct the waste into the appropriate compartment. The LCD display shows the detected waste type, and the GSM module sends an SMS notification regarding system status.

Finally, the servo returns to its initial position, and the system resets to standby mode for the next operation.

VI. COMPONENTS USED

A. Arduino Uno: Main control unit for all sensor input and actuator control.

Fig.5 Arduino Uno

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B. Moisture Sensor Module: Measures the moisture content of waste material for classification.

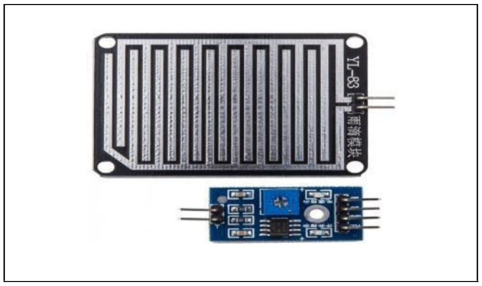

Fig.6 Moisture Sensor Module

C. Ultrasonic Sensor: Detects presence of waste.

Fig.7 Ultrasonic Sensor

D. Servo Motor: Controls the waste direction mechanism.

Fig.8 Servo Motor

E. 16×2 LCD Display: Displays waste type.

Fig.9 LCD Display

F. GSM (SIM800L) Module: Sends real-time SMS notifications.

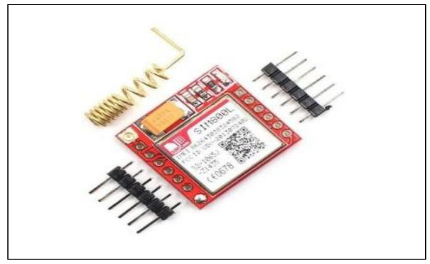

Fig.10 GSM Module

VII. HARDWARE MODEL

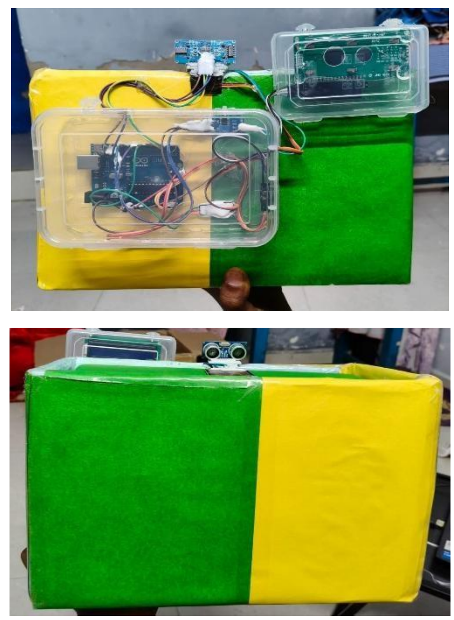

Fig.11 Hardware Model

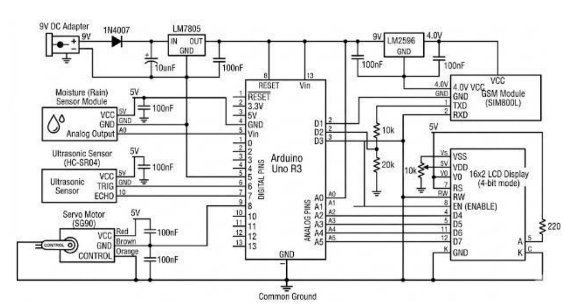

Fig.12 Circuit Diagram

VIII. ALGORITHM FOR WASTE CLASSIFICATION

Step 1: Initialize Arduino, sensors, LCD, servo motor, and GSM module.

Step 2: Detect waste object using the ultrasonic sensor. **Step 3:** Read moisture value from the moisture sensor. **Step 4:** Compare moisture value with predefined threshold.

Step 5: If moisture ≥ threshold → classify as biodegradable.

Else → classify as non-biodegradable.

Step 6: Rotate servo motor to direct waste into the appropriate bin.

Step 7: Display waste type on LCD.

Step 8: Send SMS notification through GSM module.

Step 9: Reset system for next waste input.

IX. EXPERIMENTAL SETUP

The prototype smart dustbin system was experimented in controlled environmental conditions in an indoor environment. To measure the level of moisture the moisture sensor was installed at the waste detection area and to detect the insertion of the objects the ultrasonic sensor was mounted at the top of the bin. The Arduino Uno was serially linked to the GSM module (SIM800L). The waste samples were evaluated with the help of 36 waste samples, which included organic waste, paper materials, plastics, and mixed waste items. The moisture level was experimentally adjusted and adjusted to 450 ADC units of waste classification.

X. RESULTS AND PERFORMANCE ANALYSIS

To test the performance of the proposed system on the basis of a real-world sample, several samples of waste were used. The condition of testing was normal indoor environmental.

conditions. An analogous set value of moisture presence was coded into the Arduino to categorize waste as either biodegradable or non-biodegradable.

The total number of waste samples assessed is 36, which comprised of kitchen waste materials, paper materials, plastic materials and mixed waste objects. The moisture threshold value was calibrationally determined (within a 01023 analog range) and adjusted to 450 ADC units experimentally

..

The moisture value comes out of the sensor analog output in the range of 0 -1023 ADC units and is given as:

Moisture Value = Analog Reading (0–1023) The classification decision rule is defined as:

- If Moisture ≥ 450 → biodegradable
- If Moisture < 450 → non-biodegradable

1. Sample Testing Table:

Sample No.	Waste Item	Actual Type	Predicted Type	Result
1	Banana Peel	Biodegradable	Biodegradable	Correct
2	Paper	Non-Biodegradable	Biodegradable	Incorrect
3	Plastic Bottle	Non-Biodegradable	Non-Biodegradable	Correct
4	Vegetable Waste	Biodegradable	Biodegradable	Correct
5	Cardboard	Non-Biodegradable	Non-Biodegradable	Correct
6	Orange Peel	Biodegradable	Biodegradable	Correct
7	Used Tissue Paper	Biodegradable	Biodegradable	Correct
8	Aluminum Foil	Non-Biodegradable	Non-Biodegradable	Correct
9	Plastic Cup	Non-Biodegradable	Non-Biodegradable	Correct
10	Half-dry Leaf	Biodegradable	Non-Biodegradable	Incorrect
11	Moist Paper Cup	Non-Biodegradable	Biodegradable	Incorrect

12	Plastic Wrapper	Non-Biodegradable	Non-Biodegradable	Correct
13	Coconut Shell	Biodegradable	Biodegradable	Correct
14	Apple Waste	Biodegradable	Biodegradable	Correct
15	Plastic Spoon	Non-Biodegradable	Non-Biodegradable	Correct
16	Newspaper	Non-Biodegradable	Non-Biodegradable	Correct
17	Cooked Rice	Biodegradable	Biodegradable	Correct
18	Tea Leaves	Biodegradable	Biodegradable	Correct
19	Milk Packet	Non-Biodegradable	Non-Biodegradable	Correct
20	Egg Shell	Biodegradable	Biodegradable	Correct
21	Chocolate Wrapper	Non-Biodegradable	Non-Biodegradable	Correct
22	Dry Leaf	Biodegradable	Biodegradable	Correct
23	Styrofoam Plate	Non-Biodegradable	Non-Biodegradable	Correct
24	Fruit Peels (Mixed)	Biodegradable	Biodegradable	Correct
25	Plastic Cover	Non-Biodegradable	Non-Biodegradable	Correct
26	Wet Bread	Biodegradable	Biodegradable	Correct
27	Thermocol Piece	Non-Biodegradable	Non-Biodegradable	Correct
28	Onion Skin	Biodegradable	Biodegradable	Correct
29	Plastic Straw	Non-Biodegradable	Non-Biodegradable	Correct
30	Tomato Waste	Biodegradable	Biodegradable	Correct
31	Soaked Cardboard	Non-Biodegradable	Biodegradable	Incorrect
32	Juice Carton (Wet)	Non-Biodegradable	Biodegradable	Incorrect
33	Semi-dry Vegetable Waste	Biodegradable	Non-Biodegradable	Incorrect
34	Wet Tissue	Biodegradable	Biodegradable	Correct
35	Plastic Container (with residue)	Non-Biodegradable	Biodegradable	Incorrect
36	Banana Stem	Biodegradable	Biodegradable	Correct

Fig.13 Testing Table

2. Classification Results of the Proposed System:

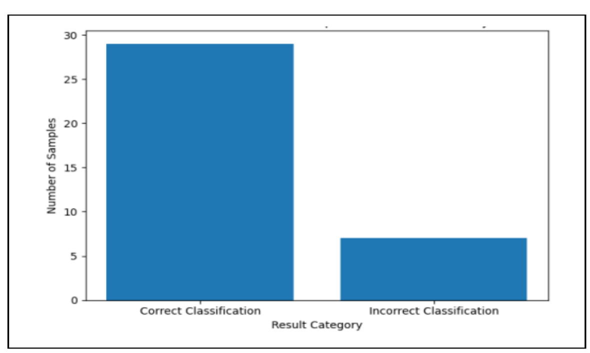

Fig.14 Bar Graph

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3. Accuracy Calculation:

Out of 36 tested samples, 29 were correctly classified. Accuracy is calculated using:

Accuracy (%) = (Correct Classifications / Total Samples) × 100

Accuracy = (29 / 36) × 100 = 80.55%

The system achieved an overall classification accuracy of 80.55%.

4. Performance Discussion:

The misclassification was mainly experienced in those instances where:

- Paper materials: the materials absorb the environmental moisture.
- Liquid residue was present in plastic containers.
- Semi-dry organic waste contained low levels of moisture.

This suggests that moisture-based classification can be effectively used to classify primary and that it needs other sensing systems to achieve better results.

XI. COST ANALYSIS

The smart dustbin system proposes a low cost and small-scale application of the device in families and facilities. Table II shows the estimated hardware cost of the system parts.

Table II: Estimated Hardware Cost

Component	Quantity	Cost (INR)
Arduino Uno	1	450
GSM Module (SIM800L)	1	350
Moisture Sensor Module	1	120
Ultrasonic Sensor (HC-SR04)	1	150
Servo Motor	1	150
16×2 LCD Display	1	180
9V DC Adaptor	1	100
Jumper Wires & Miscellaneous	—	200
Total Estimated Cost	—	**1700 INR (Approx.)**

XII. LIMITATIONS

The proposed smart dustbin system is effective in the segregation of basic waste though, as it was tested, there are certain limitations. The system uses primarily the moisture-based detection to categorize waste. Consequently, misclassification can be achieved in case non-biodegradable substances have liquid residues or the biodegradable waste is rather dry. In the example, paper materials are liable to moisture absorption and can occasionally be considered as biodegradable waste. Moreover, the existing system is structured in such a way that it only sorts two types of waste: biodegradable and non-biodegradable. Metal, glass and electronic waste are the other types of waste not identified separately. The moisture sensor readings can also be affected by the environmental factors like the humidity. Further developments can involve incorporating more sensors or smart classification algorithms in order to enhance accuracy of the system.

XIII. CONCLUSION

The paper has described the design and development of a GSM-based smart dustbin to retrieve biodegradable and non-biodegradable waste automatically through a moisture-based classification system. This system is comprised of an ultrasonic sensor to detect waste, a moisture sensor to classify the waste and an arduino Uno to process and control. Waste is sorted to a designated compartment by a servo motor, and a user presents them with an LCD display and GSM module which, in turn, transmits them SMS notifications in real-time.

The experimental assessment was done on 36 waste samples, with 29 of all samples being correctly identified, which makes the overall accuracy of 80.55. The response time was found to be about 1.5 seconds on average, which proved to be a good real time working time.

Even though the system works well in primary segregation, some limitations were noted in instances where waste products were overlapping in terms of moisture properties. The suggested system provides the low-cost, reliable and practical solution to the real-life waste segregation applications.

The GSM communication allows it to become more integrated to improve its monitoring ability even without the use of internet.

XIV. FUTURE SCOPE

The system offered can be improved further by the following ways:

- IoT-based cloud monitoring with such modules as ESP8266 or ESP32.
- Addition of image processing and machine learning methods to the sophisticated multi-class waste classification.
- Installation of solar power systems in order to transform the unit into energy-efficient and installation compatible in the outside.
- The development of a mobile application that will be used to

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monitor various smart dustbins centrally.

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