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Transforming Household Waste Management: Design and Implementation of an IOT-Enabled Smart Dustbin System

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Abstract— The Internet of Things (IoT) has empowered waste management performance through the ability to interconnect intelligent devices and share the information simultaneously. This paper presents an IoT-based Smart Dustbin, which can be utilized at the home level, where the primary purpose is to keep the level of sanitation and streamline the process of waste management.

This system consists of a battery of sensors that are interconnected with an ESP8266 microcontroller that coordinates all working processes. The ultrasonic sensor tracks the level of the fill in the bin thus eliminating cases of overflow. At the same time, a humidity sensor is used to detect the existence of moisture, thus, differentiating wet waste. In this regard, the system automatically separates biodegradable material and non-biodegradable material. Broodable waste, e.g., food remains and organic material, will be sent to a special compartment and non-biodegradable waste e.g. plastic and metal to a different repository. A servo motor opens and closes the sorting mechanisms and opening them to guarantee appropriate separation.

The dustbin creates the data which is sent to a cloud-based hosting giving the opportunity to remotely monitor and store the data. This feature will allow the users and waste management team to know the status of the bin at any time. The adoption of the smart dustbin reduces the use of manual labor and increases the level of hygiene. Also, it promotes recycling habits and will help in clean environment. All in all, the current paper offers a simple but elegant solution to the problem of making house waste management more efficient.

Keywords — IoT, Smart Dustbin, Ultrasonic Sensor, Humidity Sensor, ESP8266 Microcontroller, Waste Segregation, Servo Motor, Firebase Integration, Overflow Prevention, Smart Waste Management.

I.INTRODUCTION

Waste management must be properly done to guarantee good living standards and sustainable environmental growth. Poor disposal of waste materials puts people at high level of health risks such as infection, pollution, and chronic illnesses. The high rate of urbanization and the growth of domestic wastes have made the old waste management systems ineffective. Therefore, this necessitates the use of smart and automated technologies to ensure cleanliness and hygiene. Internet of things (IoT) is central to the revolution of modern-day waste management systems that involve linking smart devices that have a sensor, a processor, and a communication module to collect and transmit data in real time. This connectivity enables smart monitoring and automation within applications that are everyday.

This paper presents a smart dustbin based on the IoT with a special purpose of household waste management. This system is supposed to avoid overflow of bins and enhance good separation of the waste. The ultrasonic sensors will keep keeping track of the garbage in the bin. The dustbin will notify the users on time to dispose of the dustbin when the dustbin fills to 80 percent capacity. Humidity sensor differentiates biodegradable and non-biodegradable wastes. In memory of incarcerating waste to a wrong bin, there should be instant notifications to rectify the activity. WhatsApp notifications make it quick and easy to communicate.

The intelligent rubbish bin eliminates the need of humans to monitor it and ensures that the community adopts responsible waste disposal practices. Cloud connectivity allows status and performance of bins to be remotely monitored. Digital segregation advances the recycling

process and contributes to the ecological sustainability. The system also enhances the hygiene since the waste is not piled up inside the homes. The proposed model is an innovative and eco-safe model that can be used to address the challenge of smart sensors and communication tools, integrated with IoT technology. It helps to build smart houses and contemporary urbanity. On the whole, this system is a realistic solution to efficient, automated and sustainable household wastes management.

PROBLEM STATEMENT

The previous waste container handling procedures required manual checkout which was not only hectic but also ineffective. Nowadays, people live in busy and dynamic worlds, where people often forget to regularly empty receptacles, and the effect is overflow, unpleasant smell, and health risks. Furthermore, the improper separation of biodegradable and non-biodegradable refuse is also contributing to the environmental degradation and hindering the successful recycling. In order to solve these deficiencies, the proposed Internet-of-Things (IoT) smart dustbin will use automated monitoring alongside waste-management functions.

The system will be set up to produce an alarm when the receptacle occupies about eighty percent of its capacity, which will also be reported to the end- users and the city's collection operators. It also has an automatic lid-opening feature, which proves to be helpful in increasing hygienic conditions and convenience when the user is close by. Using the requirement to separate the biodegradable and non- biodegradable streams of waste, the equipment will ensure proper waste disposal and support a belief in recycling and environmental sustainability. Through a web interface operators are able to view real-time status metrics allowing them to photo surveillance of fills remotely. Timely disposal procedures and proper waste segregation, therefore, reduce the need of manual labour, minimise overflow hazards as well as create a respectable, more sustainable environment.

METHODOLOGY

Following the critical analysis of available garbage tracking devices, there is a suggestion of a smart household dustbin that will provide better waste management in terms of Internet of Things technologies usage. Its design revolves around an ESP8266, where ultrasonic sensors were used to monitor the amount of garbage contained in the receptacle at all times. Humidity sensor is installed to identify a mishandled waste that is either moisture-abundant or degradable but swollen into the wrong bin. This smart surveillance system will reduce the chances of overflow and enhance efficient waste separation. Moreover, the system provides an opportunity to receive real changes and notifications thus ensuring timely disposal and better hygienic conditions.

Hardware Components —

1) ESP8266 Microcontroller: A low-power Wi-Fi controller used for processing sensor data and enabling IoT communication.
2) Jumper Wires: Used to create reliable electrical connections between components.
3) Ultrasonic Sensor: Measures the fill level of the bin using distance detection.
4) Humidity Sensor: Detects moisture content to identify wet waste.

Software Components —

1) Frontend: Developed using HTML, CSS, and JavaScript to display real-time bin status.

2) Backend: Firebase is used for real-time database management and user authentication.

A. Sequential block diagram

The sequential block diagram shows the general working process of the suggested smart dustbin system. A sensor with ultrasonic frequency is installed inside the bin to constantly measure the area between the sensor and the waste surface which helps appropriately determine the fluff content of the container. The ESP8266 microcontroller processes the data collected and provides an opportunity to communicate via Wi-Fi to connect the process with the IoT. As a result, the system sends real-time data to the interface on the status of the bin.

There will be a humidity sensor that detects the moisture content and identifies the fact that biodegradable waste has been incorrectly dumped in the wrong bin. In case such incident happens, ESP8266 raises an alarm and notifies the user through the WhatsApp, thus, taking appropriate corrective measures in time. Together, the sensors and microcontroller can create a smart monitoring loop, which eliminates overflow, promotes appropriate segregation, and enhances the effectiveness of waste management

Fig. 1: Sequential block diagram

B. Flowchart

Flow chart explains the ongoing check-up procedure applied by the smart waste available system. The sensors attached to the receptacle are able to measure parameters of waste dynamics in an active manner. The fill volume is measured by the ultrasonic sensor, but the moisture content to identify the typology of waste is determined by the humidity sensor. Analytic processing Sensor-derived data flow continuously to an ESP8266 microcontroller. Once the measured level of waste is close to the set threshold, a real- life analysis of the condition of the bin is conducted by the system.

Once the bin reaches 80 per cent, an automatic signal goes off. Alerts are then sent promptly to the user and municipal waste collection authority through WhatsApp, and include information regarding fill level and condition of moisture. In case the non-biodegradable refuse is placed in the biodegradable compartment, the system will detect the anomaly and send an immediate remedial notification. After, the notification is received, the waste management firm will make sure that a collection vehicle is sent to empty the bin.

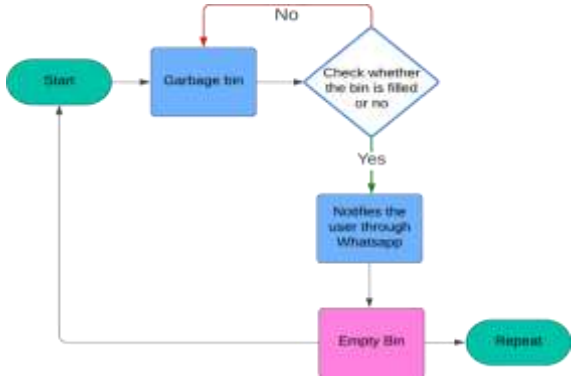

Fig 2: Flowchart

C. *Data flow*

Notations used to represent flow of data:

1. External Body
2. Data-Flow
3. Current-Process
4. Data-Store

D. Circuit Operation

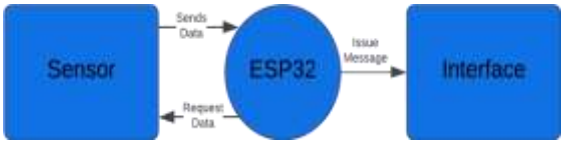

Fig. 3:Data Flow 1

Fig. 4:Data Flow 2

1) Human Presence Detection (HC-SR04-1):

The ESP8266 uses GPIO pins 25 (trigger) and 26 (echo) for an ultrasonic sensor to detect nearby objects. It sends out pulses and measures their return time to determine distance. When a person is detected, the ESP32 triggers opening the dustbin lid.

2) Trash Level Detection (HC-SR04-2):

The ESP8266 employs GPIO pins 14 (trigger) and 27 (echo) with an ultrasonic sensor to measure distances from trash. As trash accumulates, decreasing distances are detected. Upon reaching a preset level (e.g., 80% full), the ESP32 alerts both the user and the garbage collection service.

3) Waste Type Detection:

The DHT11 sensor, connected to GPIO pin 13 of the ESP8266, measures humidity levels to distinguish between degradable and non-degradable waste [1]. Higher hu- midity suggests organic waste, while lower humidity suggests inorganic waste.If there's incorrect segregation (e.g.,degradable waste in a non-degradable bin), the ESP8266 sends a WhatsApp alert to the user to ensure proper waste sorting.

4) Notifications and User Interaction:

The ESP8266 connects to Wi-Fi, enabling it to send notifi- cations via WhatsApp when the bin is full or if waste is placed in the wrong bin .] [3].Users can log into a dedicated website to check the trash level and request early emptying if it is necessary.

II. System Requirement

A. Hardware Requirements

1) Arduino UNO – Main control unit that processes sensor data and controls system operations.

2) NodeMCU (ESP8266) – Provides Wi-Fi connectivity and enables IoT communication with the cloud.

3) Ultrasonic Sensor – Measures garbage level inside the dustbin.

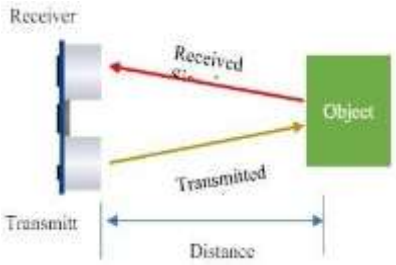

Fig. 5: UltraSonic Working

4) IR Sensor – Detects human presence for automatic lid opening.

5) Humidity Sensor – Detects wet waste and supports waste segregation.

6) Servo Motor – Used for waste separation and lid movement.

Fig. 6: Servo Motor

7) DC Motor – Controls opening and closing of the dustbin lid.

8) L293D Motor Driver – Drives and controls the DC motor safely.

9) 16×2 LCD Display – Shows real-time system status and garbage level.

10) Buzzer – Provides audible alerts when the bin is full.

11) Power Supply Unit – Provides stable voltage to all components.

12) Connecting Wires & Breadboard – For circuit connections and prototyping.

B. Software Components

1) Arduino IDE – Used to program the Arduino and NodeMCU.

2) Embedded C / Arduino Programming – Controls sensors and actuators.

3) Database – Stores real-time garbage data.

4) Web Interface (HTML, CSS, JavaScript) – Displays bin status to users.

5) WhatsApp API Integration – Sends alerts and notifications.

6) IoT Cloud Platform – Enables remote monitoring and data transmission.

III. Project Execution

The Smart Dustbin system implements strong risk-management measures in ensuring quality performance and customer satisfaction. The sensor units are also enclosed to minimize the damage that is inherent to dust, moisture, and un favourable environment. The ongoing diagnostic is a means of timely detection of faults and the provision of maintenance warning. Data privacy and integrity is maintained through encrypted communication hence protecting the privacy of the users. There is a cost-accuracy balance in the system that allows it to be deployed at strong scale.

Waste level was determined with a precision of the sensing unit of ultrasound of 5cm and moisture content was merely estimated by looking at the humidity sensor at 40% relative humidity. Alerts are sent through WhatsApp and a specific designed web portal when the bin reaches 80 1/3 rd of its capacity. The performance of waste segregation achieves a precision of about 80 -percent.

Even though cost reduction could slightly decrease sensor sensitivity, lifespan and resolution, calibration, shielding and sensor fusion strategies can be used to suppress them. The model prototype cost is between Rs1120 and 1620. Warehouse model with low cost can be achieved with a range of Rs 385 to Rs 625 and, thus, make the system affordable and extendable.

Expected Outcome

The proposed ESP8266-based smart dustbin could positively influence the household waste management process because it helps to make the process of garbage disposal cleaner, automated and efficient. There is constant observation of the levels of garbage and overflow is addressed by the use of alerts sent once the bin has reached 80% capacity. This clinical intervention is mechanistic making it easy to collect in time and maintain hygiene at the home. The wastes that contain more than 40 per cent of wet matter, are considered to be biodegradable; otherwise, they are considered to be non-biodegradable. WhatsApp notification of real-time communication and web-based monitoring ensures that users and waste authorities are updated in time, which facilitates intelligent waste management.

The system has proven to be technically feasible in terms of massive output production in a large-scale production because it depends on commercially available sensors, microcontrollers, and IoT communication modules. The design is economical and scalable hence making it receptive to a large scale deployment. The results of environmental impact assessments show that the system decreases overflow, improves the efficacy of the collection process, as well as lowers the intensity of pollution. The social feasibility is increased, with the system creating a clean and convenient environment to the end users. The regulatory compliance is ensured by the adherence to the smart-city waste-management standards and the set data-security practices in the field of IoT. This in turn makes the project to be viable, replicable and viable in practice.

Results

The application of an IoT based system of a smart dustbin shows a substantial household waste monitoring and management enhancement. In a test carried out, the ultrasonic sensor is able to detect garbage correctly and in real time, though experimental results have shown that the sensor is also consistent and efficient in making alerts when the bin is at 80 percent capacity. The WhatsApp notifications were relayed on the server to the users in a timely manner with a minimum delay to ensure that they can take necessary action in time and not allowing the overflow. The automated lid system was responsive to the human presence at all times

and could be operated touchless to provide hygienic operation.

The humidity sensor was also able to distinguish very well on biodegradable and non-biodegradable waste, and served as a good mark of automated sorting and enhancing recycling rates. Cloud integration made it possible to have real-times data visualization via a web portal which made the visualization viewable by the users and waste management authorities remotely. Reliability tests were done on the system to ensure it remains stable with continuous operation and consumes low power.

Comprehensively, the prototype minimized the manual monitoring, decreased overflow cases, and increased the hygiene of the testing environment. The findings confirm the accuracy, responsiveness, and acceptability of the proposed system in the practical implementation of smart household waste management systems.

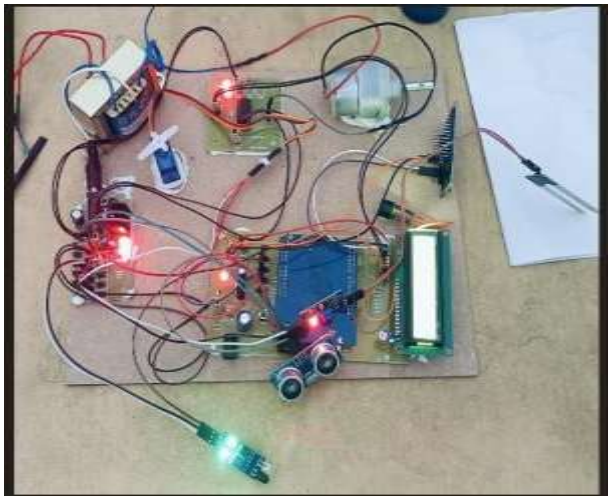

Fig. 7: Circuit Diagram

Fig. 8: LCD display VIII.FUTURE SCOPE

As recommended, the ESP32 based IoT Smart Dustbin system provides a viable and scalable approach to automatizing the process of handling household wastes. As evidenced by the experimental outcomes, the accuracy of garbage degree detection, the accuracy of waste sorting, and the effectiveness of real-time feedback made possible through cloud connectivity are proved. This application of ultrasonic and humidity sensors, automated control of the lid and remote monitoring prevents confirms the ability of the system to improve hygiene, reduce overflow conditions and encourage sustainable usage of waste products. In addition to this, the prototype architecture is both affordable and can be deployed in either the smart home or smart city environments.

It is true that future upgrades would significantly increase the intelligence and effectiveness of the system. Introducing machine-learning algorithms and computer-vision methods can help to advance waste sorting, which can enhance the accuracy of segregation compared to that with sensor-based detection only. The blockchain system can provide a method of open monitoring of the waste collection and recycling processes, creating a sense of responsibility and allowing participation due to incentives. Moreover, the analytics which takes advantage of the information stored historically about waste can streamline the collection schedule, reduce the operational expenses and guide the waste authorities in improving route planning.

Another crucial field to further development is energy resilience. Uninterrupted operation can be provided with adopting the high-capacity lithium-ions batteries, solar- charging modules as well as smart schemes of power- management. It would also enhance reliability by increasing power- backup systems that are automated and real-time diagnostic to be used during outages. Such potential enhancements make the Smart Dustbin an improved, smart dustbin platform with the potential to support the build of much-needed sustainable infrastructure.

Overall, the system provides a solid premise of the smart and data-driven waste management, and highlights the possibilities of the IoT-based integration in improving the quality of the environment and urban living.

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