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IoT Enabled Smart Bin for Waste Management with Incentivized Rewards

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Abstract

Improper waste management plagues the earth, posing serious environmental and health threats. Traditional bins lack the ability to segregate waste at the source, further exacerbating the problem. This ingenious system tackles two major challenges: inefficient waste segregation and lack of motivation for proper disposal. Equipped with sensors and camera, the smart bin automatically identifies and segregates different waste types, ensuring cleaner waste streams. The system employs a unique reward-based mechanism to incentivize responsible waste disposal. This research is mainly focused to improve the environmental sustainability by providing reward system. This reward system encourages the people to deposit plastic waste properly to the bin, hence it creates a disposal behaviour among the public.

Keywords: Waste management, Sensors, Camera, Incentives, Sustainability

1. Introduction

In the rise of escalating environmental concerns, the urgency to revolutionize waste management practices has reached unprecedented heights [9]. Amidst this call for action, the emergence of the IoT-enabled smart bin equipped with advanced plastic and other waste sorting capabilities, coupled with user incentives, emerges as a beacon of hope in the battle against plastic pollution and waste mismanagement. By leveraging the convergence of IoT technology, image processing, and real-time garbage level identification, these intelligent bins not only streamline waste sorting processes but also empower individuals to actively contribute to a more sustainable future [10]. At its essence, the IoT-enabled smart bin represents a paradigm

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shift in waste management, transcending the limitations of traditional receptacles through its integration of cutting-edge technology [11]. Equipped with sophisticated sensors and image processing algorithms, these bins possess the ability to distinguish between various types of waste, including plastics and other recyclables, thereby facilitating efficient sorting at the point of disposal. Real-time garbage level identification further enhances operational efficiency by optimizing collection routes and resource allocation, minimizing logistical costs, and reducing environmental impact [12]. Central to the efficacy of the IoT-enabled smart bin is its capacity to incentivize user participation in plastic waste management. By gamifying the waste disposal process and offering tangible rewards or incentives for the deposit of plastic waste, these bins foster a culture of environmental responsibility and stewardship among individuals [13]. Whether through loyalty points, discounts at local businesses, or charitable donations, user incentives serve as powerful motivators to encourage sustainable behaviors, driving positive environmental outcomes and community engagement. Moreover, the integration of IoT technology and real-time data analytics transforms these smart bins into dynamic tools for municipal authorities and urban planners [14]. By aggregating and analysing data on waste generation patterns, recycling rates, and disposal trends, these bins provide valuable insights that inform evidence-based decision-making and policy formulation. From optimizing waste collection schedules to identifying opportunities for targeted interventions and infrastructure improvements, the actionable intelligence derived from smart bin data empowers cities to enact meaningful change and progress towards sustainability goals. However, the widespread adoption and implementation of IoT-enabled smart bins are not without challenges and considerations. Technical complexities, including interoperability, connectivity, and cybersecurity, must be addressed to ensure seamless integration into existing waste management infrastructure. The IoT-enabled smart bin represents a transformative force in the realm of waste management, offering a comprehensive solution to the pervasive challenges of plastic pollution and waste mismanagement. By harnessing the power of IoT technology, image processing, and user incentives, these intelligent bins empower individuals to take an active role in shaping a more sustainable future. As we navigate the complexities of the 21st century, the IoT-enabled smart bin stands as a testament to the potential of innovation, collaboration, and collective action in combatting environmental degradation and fostering global resilience[15].

2. Background

2.1 Python

Python is highly useful in coding IoT projects due to its simplicity, versatility, and extensive libraries. It facilitates rapid development of IoT applications, offering support for device communication, data processing, cloud integration, and machine learning.

2.2 ESP32 Dev Kit

The ESP32 Dev Kit is a development board based on the ESP32 system-on-chip (SoC) manufactured by Espressif Systems. The ESP32 is a popular microcontroller that offers both Wi-Fi and Bluetooth connectivity, making it suitable for a wide range of IoT (Internet of Things) and embedded projects.

3. Related Work

This paper focuses on classifying waste at the edge within smart bins using sensors and edge computing. It involves deploying sensors and edge devices for data collection. The relevance of the project is to improve efficiency, reduce data costs, enhance responsiveness, and address privacy and security concerns in waste management systems [1].

The paper displays the waste level percentage and regulates the collection schedule with the concerned authorities. The merits of the project are efficiency, real-time monitoring, and environmental benefits; the demerits are that it does not sort the waste items. It reduces environmental impact and be cost-efficient [2].

The paper [3] sorts the recyclable bottles and papers using sensors, cameras, and the user can control the system through the user interface and data logging record sorting. By efficiently separating recyclables from non-recyclables at the source, it reduces contamination, promotes recycling, and conserves resources. The merits of the project are lower latency and energy efficiency, and the demerits are maintenance challenges, dependency on local AI models, and potential security risks.

The paper [4] sends the data to a cloud platform for processing. The user interface allows real-time monitoring and alerts for waste collection. It promotes recycling, minimizes environmental impact, engages communities, enables data-driven decisions, and provides economic benefits. The merits of the project are improved efficiency, real-time monitoring, and waste sorting. And the demerits are initial costs, maintenance requirements, and data privacy concerns.

This paper [5] involves selecting suitable sites and bins, enabling IoT connectivity, and employing data analytics for efficient waste collection. It has improved efficiency, conserved resources, reduced environmental impact, and raised public awareness. The merits of the project are waste sorting, environmental benefits, and public engagement, and the demerits are maintenance challenges, data privacy concerns, and ensuring a stable power supply.

This paper [6] involves assessing local waste management needs, equipping bins with sensors, and optimizing waste collection routes. They address growing urbanization and public health concerns and provide valuable data-driven insights for informed decision-making. The merit of the project is real-time monitoring and proactive maintenance, and the demerit is complexity of technology has limited coverage in some areas.

This paper sorts domestic waste into metallic, plastic, and glass categories. It is applied to better globalization with waste management solutions. The merit of the project is that a that a waste tracker is included, and the demerit is that plastic and paper cannot be sorted simultaneously [7].

This paper gives a real-time indication of the garbage level. In urbanized areas, it allows the trash collectors to plan their daily or weekly pickup schedule. The merit of the project is to reduce fuel consumption for waste collectors, and the demerit is technical complexity and limited coverage in some areas [8].

4. Preliminaries

4.1 Data Collection

The data collection phase of a smart bin with waste sorting and user incentives involves IoT sensors and image processing to gather information on deposited waste. As users dispose of plastic waste, IoT sensors detect the presence of items in the bin. Simultaneously, image processing technology analyzes images of waste to classify materials accurately. These data points, including the type and quantity of plastic waste deposited, are collected and transmitted for analysis.

4.2 Training phase

In the training phase, a smart bin with waste sorting and user incentives utilizes an existing dataset of labeled images of plastic waste. By leveraging the pre-existing dataset, the system accelerates to accurately identify and sort plastic waste, enhancing user engagement. With an already-trained dataset, the system identifies a limited type of waste and processes the information.

4.3 Testing Phase

Various aspects are evaluated to ensure the system's functionality and reliability. This includes testing the accuracy of sensors in measuring fill levels and detecting different types of waste, assessing the communication and data transmission capabilities of the bins, and verifying the effectiveness of algorithms in predicting optimal collection schedules and routes. Field tests may involve placing smart bins in real-world environments to simulate different usage scenarios and challenges.

5. System Components

The system components of the Smart Bin include:

5.1 ESP32 Dev Kit

In this microcontroller helps to receive the data from the sensors and other devices and sends it to microcontroller (ESP 32 Dev Kit). The programming is done using the Arduino IDE, PlatformIO, Espressif's ESP-IDF (IoT Development Framework), and other development environments. It supports the C/C++ programming language. It typically includes the ESP32 SoC, onboard power regulation, GPIO pins exposed for easy access, and a USB-to-Serial converter for programming and debugging. The integrated Wi-Fi and Bluetooth capabilities of the ESP32 make it suitable for projects that require wireless communication.

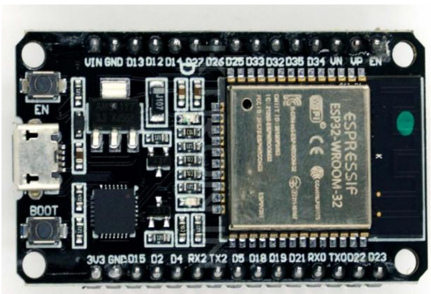

Figure 1. ESP Dev Kit

5.2 Gear Motor

DC gear motors are electrical devices that convert electrical power from a 12-volt direct current (DC) source into mechanical motion. These motors are commonly used in a wide range of applications where low voltage operation and precise control of speed and torque are required. The addition of a gear mechanism allows these motors to deliver higher torque outputs at lower speeds.

Figure 2. Gear Motor

5.3 I2C LCD

A 16x2 LCD (Liquid Crystal Display) is a common type of alphanumeric display module that can display two lines of text, with each line containing up to 16 characters. These displays are widely used in various electronics projects, devices, and applications for displaying information to users. The HD44780 controller supports a set of commands that can be sent from a microcontroller to control the display, cursor position, clearing the display, and more.

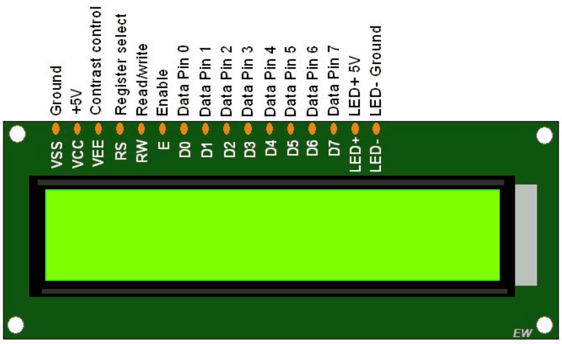

Figure 3. I2C LCD

5.4 Relay Module

A relay is an electrical or electromechanical device that is used to control a circuit remotely by opening or closing contacts in response to an input signal. Relays are commonly used in various applications to isolate high-voltage circuits from low-voltage control circuits, to switch power to different components, and to control complex systems.

Figure 4. Relay Module

5.5 Servo Motor

A servo motor is a type of electric motor that is designed to provide precise control over angular or rotational movement. It is commonly used in various applications that require accurate positioning, such as robotics, CNC machinery, remote-controlled vehicles, cameras, and more. When connecting a servo motor to a microcontroller or any control system, make sure you connect the power supply pins correctly to provide the appropriate voltage and current, and connect the control signal pin to the appropriate PWM output pin on your microcontroller. Some servo motors include a feedback pin that provides information about the current position of the motor's shaft. SG90 servo motor operates by converting electrical signals (PWM) into precise mechanical movement. The control circuit and gearing system work together to accurately position the output shaft according to the incoming control signal. While the SG90 is a simple and popular servo motor, more advanced models may include additional features like feedback mechanisms for increased accuracy.

Figure 5. Servo Motor

5.6 Ultrasonic Sensor

Ultrasonic sensors are widely used in various applications such as distance measurement, object detection, obstacle avoidance, level sensing, and more. They work by emitting ultrasonic waves and measuring the time it takes for the waves to bounce off an object and return to the sensor. Based on this time delay, the distance to the object can be calculated using the speed of sound in air. The working of an ultrasonic sensor is based on the emission and reception of high-frequency sound waves, typically in the ultrasonic range (above the human audible range). These sensors are commonly used for distance measurement, object detection, and navigation.

Figure 6. Ultrasonic sensor

5.7 Web Camera

A webcam is a video camera that feeds or streams an image or video in real time to or through a computer to a computer network, such as the Internet. Webcams are typically small cameras that sit on a desk, attach to a user's monitor, or are built into the hardware. Webcams can be used during a video chat session involving two or more people, with conversations that include live audio and video.

6. System Architecture

The system architecture (Figure.7) for a smart bin project comprises hardware components such as sensors for detecting fill levels and weight, alongside microcontrollers or single-board computers for data processing. A communication module enables connectivity, either through Wi-Fi, Bluetooth, LoRa, or GSM, facilitating data transmission to a central server or cloud platform. Data processing and storage occur either locally or in the cloud, where initial analysis may take place. Users interact with the system through a user interface, typically a mobile or web app, allowing them to monitor bin status and receive alerts. Cloud infrastructure supports scalability, real-time data processing, and remote access, ensuring efficient management of waste disposal.

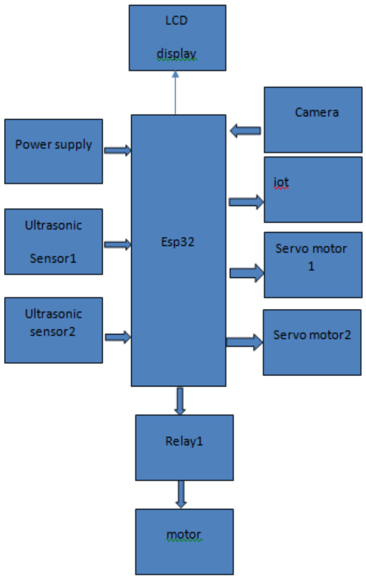

Figure 7. System Architecture

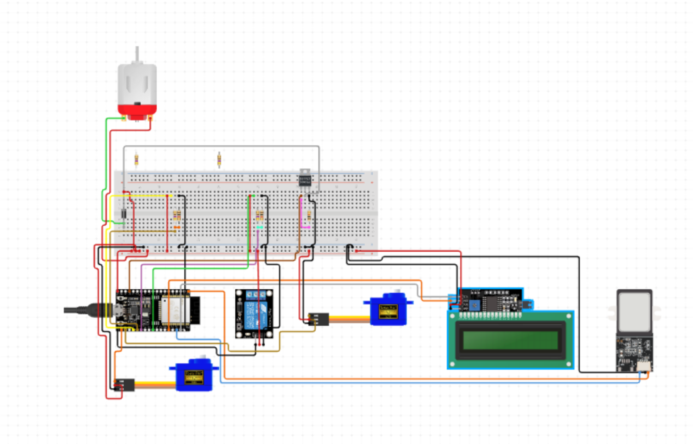

Figure 8. Circuit Diagram

- **System Implementation**

1. **Hardware**: The Arduino board consists of a microcontroller (the brain of the board), digital and analog input/output pins, power connectors, USB interface (for programming and communication with the computer), and various other components such as voltage regulators, crystal oscillators, and LEDs.

2. **Software**: Arduino uses a simplified version of C/C++ programming language. The programs for the smart bin (called sketches) are written using C++ in the Arduino Integrated Development Environment (IDE uploaded to the Arduino board through USB.

3. **Sketch Execution**: Once uploaded, the sketch is stored in the flash memory of the microcontroller. Upon power-up or reset, the microcontroller executes the sketch stored in its memory. The sketch typically contains setup () and loop () functions. The setup () function runs once at the beginning of the program and is used for initialization tasks such as configuring pins and variables. The loop () function runs repeatedly for the duration of the program and contains the main logic of the program.

4. **Interfacing with Hardware**: The Arduino board based on the code interacts with various electronic components that are used in the proposed work for e.g sensors, actuators, motors, LEDs, displays, etc. This is achieved by connecting these components to the input/output pins of the Arduino board. The code in the sketch helps to read data from sensors, control actuators, and perform desired actions based on input and conditions.

5. **Communication**: Arduino boards can communicate with other devices or microcontrollers using various communication protocols such as Serial (UART), SPI, I2C, etc. This allows Arduinos to interact with other Arduinos, computers, or external modules.

6. **Sensor Integration**: The smart dustbin would be equipped with sensors to detect the waste level inside the bin. These sensors could be ultrasonic sensors, infrared sensors, weight sensors, or any other suitable sensor technology. The sensors continuously monitor the waste level and send this data to the microcontroller or processing unit of the smart dustbin.

7. **Microcontroller Processing**: The microcontroller receives data from the sensors and processes it. It determines the waste level based on the data received. Additionally, if the smart dustbin has a reward system, the microcontroller also manages the reward status and levels based on predefined criteria, such as the amount of waste disposed of or user engagement.

8. **LCD Display**: The waste level and reward status are then displayed on the LCD screen. The microcontroller sends the relevant information to the LCD display, which visually represents the waste level (e.g., using a progress bar or numerical value) and the reward status (e.g., icons indicating reward levels or textual messages).

9. **User Interaction**: Users can easily monitor the waste level and reward status displayed on the LCD screen. This information can encourage users to properly dispose of waste and participate in the reward system if applicable.

10. **Updates and Alerts**: The microcontroller continuously updates the LCD display as the waste level changes. It may also provide alerts or notifications on the display when certain thresholds are reached, such as when the bin is full and needs to be emptied or when a user earns a reward.

11. **Power Management**: To conserve power, the LCD display may be programmed to turn off after a period of inactivity or only activate when there is a change in the waste level or reward status. This helps prolong the battery life or reduce energy consumption if the smart dustbin is connected to a power source.

- **Mechanical Setup**

1. **Camera System:** Install one or more cameras positioned to capture images of objects as they are placed into the segregation area. The cameras should have suitable resolution and optics to capture clear images of the objects.

2. **Image Processing Software:** Develop or utilize image processing software that can analyze the images captured by the cameras. This software should be capable of:

    - Identifying and recognizing objects in the images.
    - Classifying objects as reusable or non-reusable based on predefined criteria. This classification can be done using machine learning algorithms trained on a dataset of reusable and non-reusable objects.
    - Providing coordinates or bounding boxes around the identified objects for further processing.

3. **Mechanical Sorting Mechanism:**

    - Conveyor Belt: Objects placed on a conveyor belt can be moved through the system.
    - Actuators: Use actuators such as pneumatic cylinders or servo motors to control gates, chutes, or other mechanical components for sorting.

- Sorting Bins: Set up separate bins or compartments for collecting reusable and non-reusable objects.

4. **Integration:**

- Interface the image processing software with the mechanical components. The software should send instructions to the actuators based on the classification of objects in the images.
- Activate the sorting mechanism to divert objects into the appropriate bins based on the classification determined by the image processing software.

5. **Feedback and Calibration:**

- Implement feedback mechanisms to ensure accurate sorting. For example, sensors can verify whether objects are sorted correctly and provide feedback to the system for adjustments if needed.
- Periodically calibrate the system to maintain accuracy. This may involve adjusting camera settings, updating classification algorithms, or fine-tuning mechanical components.

6. **Safety Measures:**

- Implement safety features to prevent accidents, such as emergency stop buttons and safety guards around moving parts.
- Ensure that the system complies with relevant safety standards and regulations.

7. **Testing and Optimization:**

- Conduct thorough testing of the system to verify its performance under various conditions.
- Optimize the system parameters, such as camera settings, image processing algorithms (CNN in case of proposed, and mechanical adjustments, to improve sorting accuracy and efficiency

7. Evaluation

The object detection in the proposed system is performed by training YOLOv5 with images of randomly collected waste samples. Table 1 below displays the number of sample images collected for each type of waste. The user interface was developed using React to visualize the detected objects, the waste level collected, and the rewards achieved.

Table 1. Dataset

Wastes products images	Number of samples
Plastics	150
Fruits	100
Vegetables	175
Metal	50
Glass	35
Rubber	55
Synthetic Fabrics	20

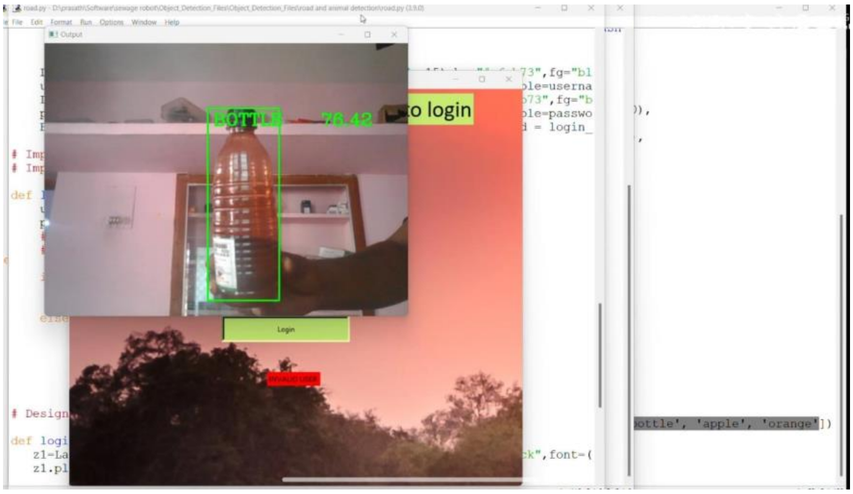

Figure 9. Training the Dataset

The figure (Figure 9) illustrates the process of training the data set of plastic.

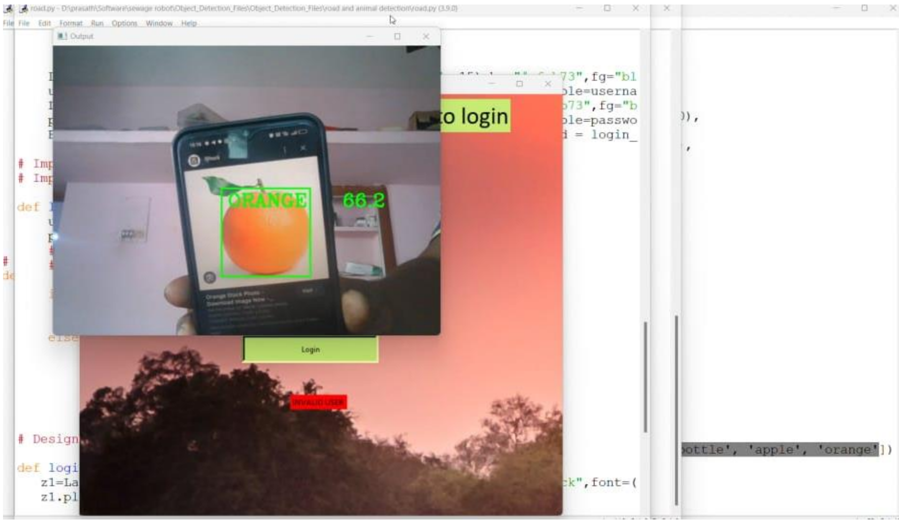

Figure 10. Dataset Training

Figure (Figure 10) illustrates the process of Training the Data set of other wastes.

For training a smart bin project dataset, it includes images or sensor data of various types of waste items commonly encountered, such as plastic bottles, paper, glass, metal cans, organic waste, etc. Each item should be labeled accurately to teach the system to recognize and classify them correctly. Additionally, you might want to include data on different environmental conditions that could affect recognition accuracy, such as lighting variations or bin locations. This diverse dataset will help the smart bin system learn to identify and sort different types of waste effectively

Figure 11. Image of Smart Bin Prototype

Figure (Figure 11) demonstrates the resultant prototype of smart bin project.

8. Future Works

The future scope of the smart bin project includes adding the capability to detect and differentiate types of plastics, enabling a reward system based on the value of the plastic. The system can also incorporate plastic recycling and crushing functionalities. Additionally, a sorting system can be integrated to handle wet waste, while solar power can be implemented to power the system. Furthermore, bio waste can be utilized for generating bio-gas.

9. Conclusions

In conclusion, the smart waste bin system offers a transformative solution to the inefficiencies inherent in traditional waste management practices. Through the integration of IoT technology, ultrasonic sensors, and data analytics, the system enables real-time monitoring, remote management, and optimization of waste collection processes. By continuously monitoring fill levels and analyzing historical data, municipalities can make proactive and data-driven decisions, leading to more efficient route planning, resource allocation, and cost-effectiveness. The system's automatic notifications facilitate timely waste collection, reducing overflowing bins and mitigating environmental hazards. Moreover, by promoting community engagement and awareness, the system encourages responsible waste disposal practices, fostering a culture of sustainability. In essence, the smart waste bin system represents a vital step towards building resilient, efficient, and sustainable urban environments in the face of growing urbanization and environmental challenges.

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