FINAL PROJECT REPORT

IoT-based Smart Waste Management System with Reward System

Course Code: CSE 460
Course Title: IOT Laboratory

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May 22, 2025

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1. Abstract

This project presents an IoT-based smart waste management system designed to incentivize proper waste disposal through a reward mechanism. Built around an ESP32 microcontroller, the system integrates ultrasonic sensors for real-time fill level detection, an RFID reader for user identification, and a servo motor for automated lid operation. The system connects to the Blynk IoT platform for remote monitoring and data management, complemented by a web application developed using HTML, CSS, and React.js for an enhanced user interface. By rewarding users with points for waste disposal, this system aims to promote responsible waste management practices while providing actionable insights for waste collection optimization.

2. Introduction

In today's rapidly urbanizing world, waste management has emerged as a pressing challenge, particularly in densely populated urban environments where rising populations and shifting consumption patterns generate ever-increasing volumes of waste. According to the World Bank, global waste production is expected to surge by 70% by 2050, with cities bearing the heaviest burden of this escalation. This growing crisis threatens not only the cleanliness and livability of urban spaces but also the sustainability of municipal resources and the health of the environment. Traditional waste management systems, which rely on static collection schedules and manually monitored bins, are increasingly inadequate in the face of this mounting pressure. Conventional waste bins lack the ability to adapt to fluctuating waste levels, often resulting in overflow, littering, and unsanitary conditions that degrade public spaces. Furthermore, the inefficiencies of these systems—such as collection trucks dispatched to half-empty bins or delayed responses to overflowing ones—waste time, fuel, and taxpayer money, exacerbating both economic and environmental strain.

To tackle these persistent shortcomings, this project introduces an innovative IoT-based smart waste management system that leverages the power of Internet of Things (IoT) technology to create a dynamic, automated, and user-engaged solution. IoT refers to a network of interconnected devices that communicate and share data over the internet, enabling real-time monitoring, intelligent automation, and informed decision-making. By integrating IoT into waste management, this system reimagines the humble waste bin as a "smart bin"—an intelligent device capable of responding to its surroundings, optimizing waste collection, and encouraging sustainable behavior among users.

The smart bin at the heart of this system is equipped with a suite of advanced features designed to address the limitations of traditional waste management:

- **RFID Authentication:** Users access the bin by scanning a unique RFID card, ensuring that only authorized individuals can dispose of waste. This feature promotes accountability and allows the system to track individual usage patterns, laying the groundwork for personalized feedback and incentives.

- **Sensor-Based Monitoring:** Two ultrasonic sensors measure the bin's fill level in real time by calculating the distance from the lid to the waste surface. These sensors provide accurate data, even when waste is unevenly distributed, enabling precise tracking of capacity and timely collection.
- **Automated Operation:** Upon successful RFID authentication, a servo motor opens the bin's lid automatically, offering a touchless and hygienic disposal experience. The lid closes after a set duration, balancing convenience with sanitation.
- **Reward System:** To motivate responsible waste disposal, users earn points based on their contributions. The system compares fill levels before and after each disposal, awarding points—such as 10 points for a significant increase (e.g., 1 cm or more)—which are then displayed on a leaderboard. This gamified approach fosters engagement and competition, driving positive behavior change.
- **IoT Connectivity and Web Interface:** The smart bin connects to the Blynk IoT platform, transmitting real-time data on fill levels and user points to a centralized server. A custom web application, built with HTML, CSS, and React.js, provides an intuitive interface for users and administrators to monitor bin status, track points, and view rankings, enhancing accessibility and system oversight.

This IoT-based smart waste management system offers a transformative approach to urban waste challenges. By enabling dynamic collection schedules based on real-time fill data, it optimizes resource use and reduces operational costs. The reward system engages users, turning a mundane task into an interactive experience that promotes sustainability. Meanwhile, the web interface and IoT connectivity ensure scalability, making the system adaptable to diverse settings—from residential neighborhoods to bustling city centers. In essence, this project not only addresses the practical inefficiencies of traditional waste bins but also paves the way for smarter, more sustainable urban living.

3. Objective

The primary goals of this project are:

1. To design an automated waste bin that opens upon user authentication using RFID technology.
2. To monitor the bin's fill level in real-time with ultrasonic sensors.
3. To implement a reward system that assigns points to users based on their waste disposal contributions.
4. To develop a user-friendly web interface for tracking bin status, user points, and leaderboard rankings.
5. To create a cost-effective and scalable solution suitable for deployment in various settings.

4. Methodology

The development of this system is divided into hardware and software components.

4.1 Hardware Development

The hardware setup consists of the following components:

- **ESP32 Microcontroller:** Acts as the central processing unit, managing sensor data, RFID authentication, servo control, and WiFi communication with the Blynk server.
- **Ultrasonic Sensors (HC-SR04):** Two sensors measure the distance from the sensor to the waste surface, enabling accurate fill level calculation by averaging their readings.
- **RFID Reader (MFRC522):** Identifies users by reading unique RFID tags associated with their accounts.
- **Servo Motor (SG90):** Automates the bin lid's opening and closing based on user authentication.
- **Power Supply:** Provides power to the ESP32 and connected peripherals, typically through a USB connection or external battery.

4.2 Software Development

The software architecture comprises two main parts:

4.2.1 Embedded Software

Written in C++ using the Arduino IDE for the ESP32. Key functionalities include:

- Reading and averaging data from two ultrasonic sensors to calculate the bin's fill level.
- Detecting and validating RFID tags for user identification.
- Controlling the servo motor to manage lid operation.
- Sending fill level data and leaderboard updates to the Blynk server via virtual pins.
- Implementing reward logic by comparing fill levels before and after disposal to award points.

4.2.2 Web Application

Developed using HTML, CSS, and React.js for the frontend, with Blynk serving as the backend. The web application provides:

- Real-time display of bin fill levels.
- User points tracking and leaderboard visualization.
- Additional features such as user registration and bin status monitoring.

The Blynk platform facilitates communication between the hardware and the web application, storing data and enabling remote access through its app and API.

5. System Operation Flow

The system operates in a logical sequence to manage waste disposal efficiently while rewarding user participation. The following steps describe the complete process flow:

1. **Start/ Idle State:** The system begins in an idle state, continuously monitoring for any user interaction via RFID scanning.
2. **RFID Card Scanning:** When a user approaches, they scan their RFID card at the reader attached to the system.
3. **User Authentication:** The system checks the scanned RFID tag against its database of registered users.
    - **Invalid Card:** If the RFID is not recognized, the system displays the message `"Unknown card"` and transitions back to the idle state.
    - **Valid Card:** If the RFID matches a registered user, the process continues to the next step.
4. **Lid Activation:** Upon successful authentication, a servo motor is triggered to open the bin lid automatically, providing a hands-free and hygienic experience.
5. **Wait Timer:** The lid remains open for a fixed duration of 7 seconds to allow the user sufficient time to dispose of waste.
6. **Lid Closure:** After the wait period, the servo motor closes the lid automatically, preparing the system for the next step.
7. **Fill Level Measurement:** An ultrasonic sensor measures the fill level inside the bin to detect whether new waste has been added.
8. **Reward Evaluation:** The system evaluates the change in fill level:
    - **Significant Increase (¿=1 cm):** The user is awarded 10 points for contributing waste.

- **No Significant Change:** No points are awarded if the increase in fill level is insufficient.

9. **Leaderboard Update:** If points are awarded, the user's score is updated and reflected on the leaderboard via the Blynk platform.
10. **Data Logging:** Regardless of reward status, the updated fill level data is transmitted to Blynk for remote monitoring and analytics.
11. **Return to Idle:** After all processes are complete, the system returns to its idle state, ready for the next user interaction.

This flow ensures a seamless, touchless experience while rewarding users for contributing to waste management. The flowchart of this project is given below:

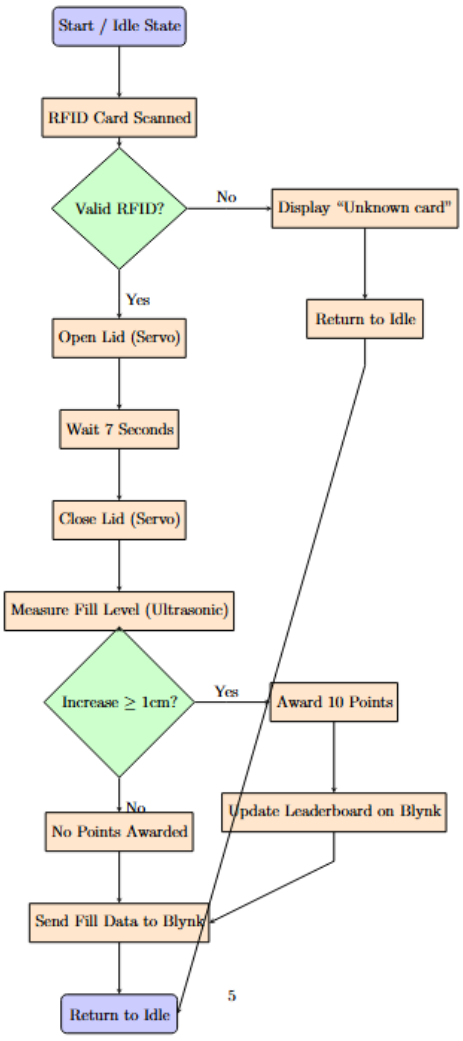

Figure 5.1: System Flowchart of IoT-Based Smart Waste Management System with Reward System

The following flowchart illustrates the process of a smart waste bin system using an RFID-based reward mechanism. Each step is described below:

- **Start / Idle State:** The system remains in an idle state awaiting user interaction.
- **RFID Card Scanned:** When a user scans their RFID card, the system reads the card's data.
- **Valid RFID?:** A decision block checks whether the scanned RFID card is valid.
  - **No:** The system displays "Unknown card" and returns to the idle state.
  - **Yes:** The system proceeds to operate the bin.
- **Open Lid (Servo):** If the RFID is valid, the lid of the bin opens using a servo motor.
- **Wait 7 Seconds:** The system waits for 7 seconds, allowing the user to dispose of the waste.
- **Close Lid (Servo):** After waiting, the lid automatically closes.
- **Measure Fill Level (Ultrasonic):** The system measures the bin's fill level using an ultrasonic sensor.
- **Increase $\geq$ 1cm?:** A decision block checks whether the fill level has increased by at least 1 cm.
  - **Yes:** The user is awarded 10 points, and the leaderboard on the Blynk platform is updated.
  - **No:** No points are awarded.
- **Send Fill Data to Blynk:** Regardless of the reward status, the updated fill level data is sent to the Blynk IoT platform.
- **Return to Idle:** Finally, the system returns to the idle state, ready for the next user.

This flowchart effectively models the smart bin's automation and reward logic, encouraging users to dispose of waste properly through gamification.

6. Circuit Diagram

The following describes the connections between the ESP32 microcontroller and the peripheral components of the smart bin system.

6.1 ESP32 Pin Configuration

- **GPIO5** — Trigger pin of Ultrasonic Sensor 1
- **GPIO4** — Echo pin of Ultrasonic Sensor 1
- **GPIO27** — Trigger pin of Ultrasonic Sensor 2
- **GPIO26** — Echo pin of Ultrasonic Sensor 2
- **GPIO21** — SDA pin of RFID Reader
- **GPIO22** — SCL pin of RFID Reader
- **GPIO13** — Signal pin of Servo Motor

6.2 Ultrasonic Sensors (HC-SR04)

- **VCC** to **5V**
- **GND** to Ground
- **Trigger/Echo** pins connected as specified above

6.3 RFID Reader (MFRC522)

- **VCC** to **3.3V**

- **GND** to Ground
- **SDA** to **GPIO21**
- **SCL** to **GPIO22**

6.4 Servo Motor (SG90)

- **VCC** to **5V**
- **GND** to Ground
- **Signal** to **GPIO13**

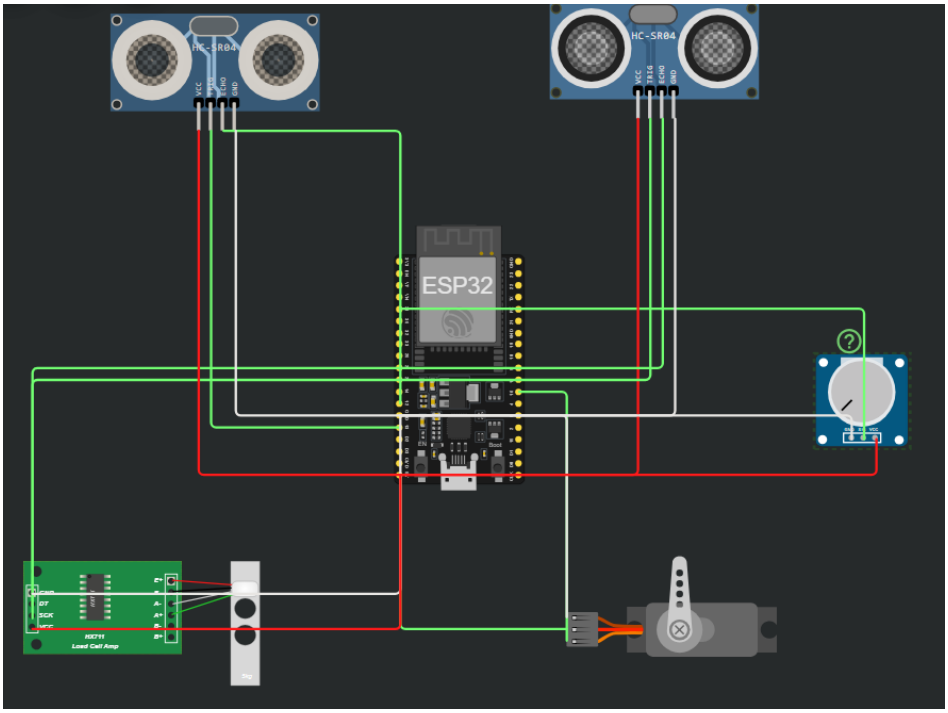

Figure 6.1: Circuit Diagram of IoT-Based Smart Waste Management System with Reward System

7. Features and Functionalities

The smart waste bin system integrates several technological components and user-centered features to improve efficiency and engagement. The key features are as follows:

- **User Authentication:** RFID cards restrict access to only registered users, ensuring secure and authorized use of the system.
- **Automated Lid Operation:** The lid opens and closes automatically using a servo motor, promoting touchless interaction to enhance hygiene and user convenience.
- **Fill Level Monitoring:** An ultrasonic sensor monitors the fill level in real-time, enabling timely maintenance and preventing overflows.
- **Reward System:** Users earn points based on the amount of waste they contribute, incentivizing responsible disposal behavior.
- **Leaderboard:** A real-time leaderboard displays user rankings, encouraging participation through friendly competition.
- **Remote Monitoring:** Integration with the Blynk platform and a web application allows remote monitoring of bin status and user activity.
- **Scalability:** The system is designed to scale easily, supporting multiple bins managed centrally via the web platform.

8. Web Application Interface

8.1 Web Interface

The web interface for the **Smart Dustbin** system is designed for use in modern web browsers, ensuring accessibility across various devices. It features a clean, centered layout with a light background and a card-based design that enhances user readability and interaction.

8.1.1 Login Page

The login page includes a simple form centered on the screen where users enter their RFID UID (e.g., `A15A893F`) into a light gray input field. A blue **Login** button is provided to complete the login process.

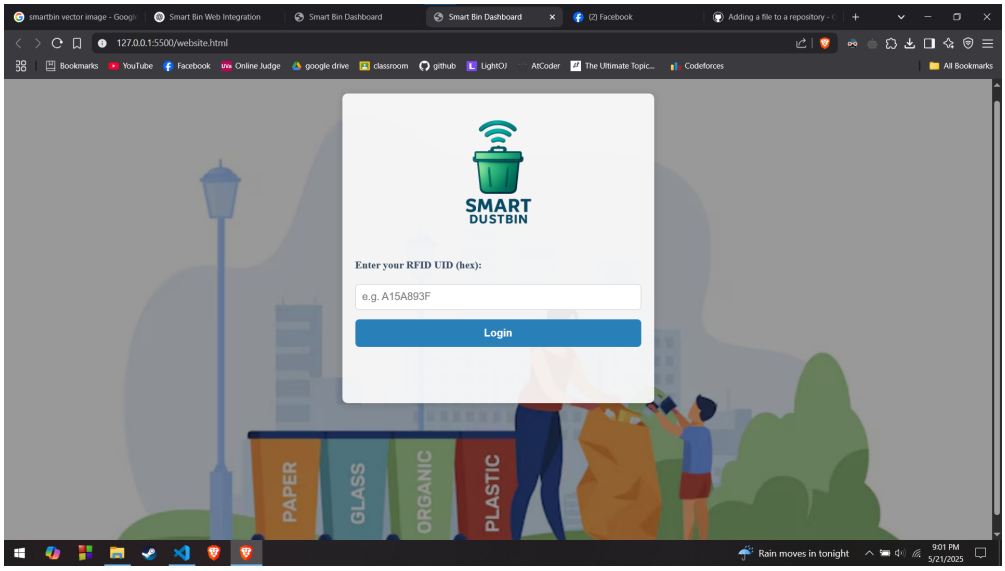

Figure 8.1: Login Interface

8.1.2 Dashboard

After successful login, users are presented with a dashboard that displays key data:

- **User Details:** Example: *User: Mahfuz Anam*, accompanied by an avatar.
- **Bin Fill Level:** Example: *Bin Fill Level: 2.78%*, indicated with a green bin icon.
- **Points Earned:** Example: *Your Points: 30 pts*, displayed with a trophy icon.
- **Logout Button:** A red **Logout** button allows the user to exit the session.

The interface emphasizes clarity and ease of access to critical information.

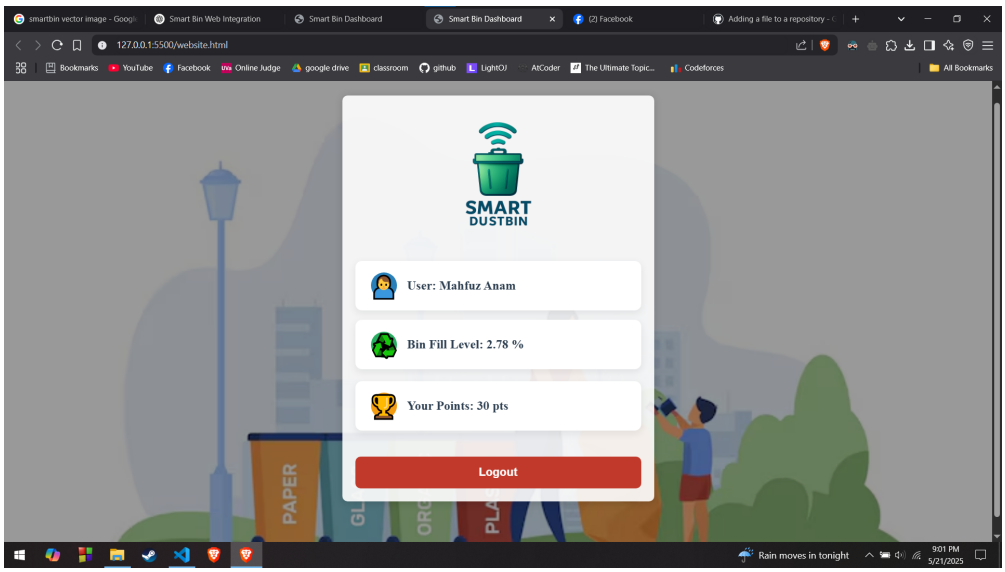

Figure 8.2: Dashboard

8.2 Mobile Application Interface

The mobile application interface of the **Smart Dustbin** system is optimized for smaller screens, offering a vertical and compact layout that retains the same design principles as the web version for a seamless user experience.

8.2.1 Layout

The mobile layout is touch-friendly and flows vertically to fit mobile display sizes, ensuring ease of navigation and interaction.

8.2.2 Components

The interface includes the following components:

- **RFID Login Screen:** Mimics the functionality and style of the web version, adapted for mobile input.
- **Dashboard:** Displays user details, bin fill level, and points. These elements are resized and arranged vertically to suit smaller displays.

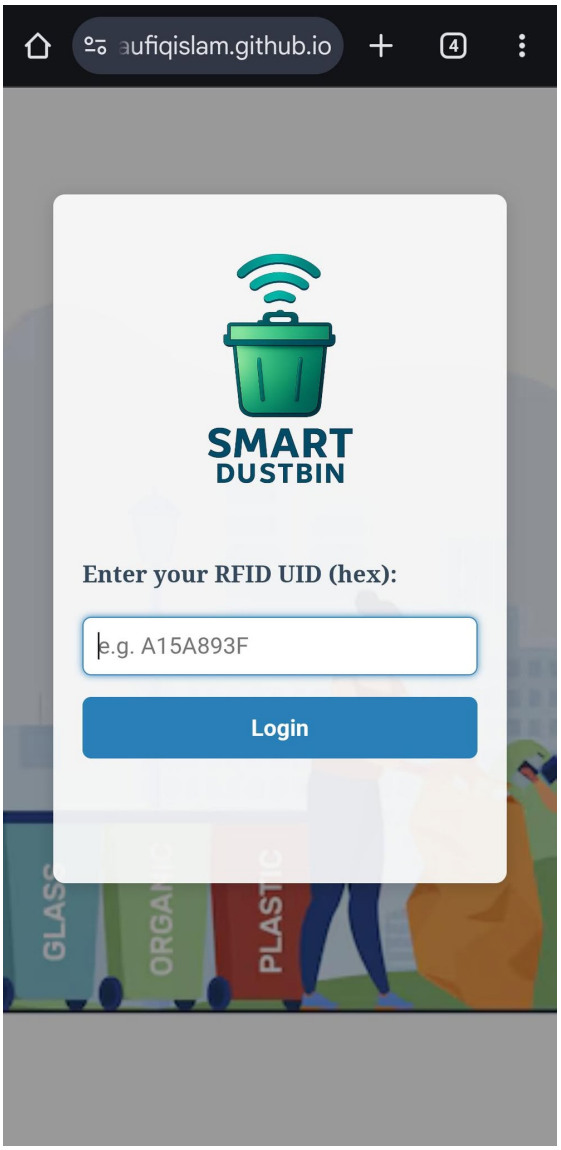

Figure 8.3: Login Interface

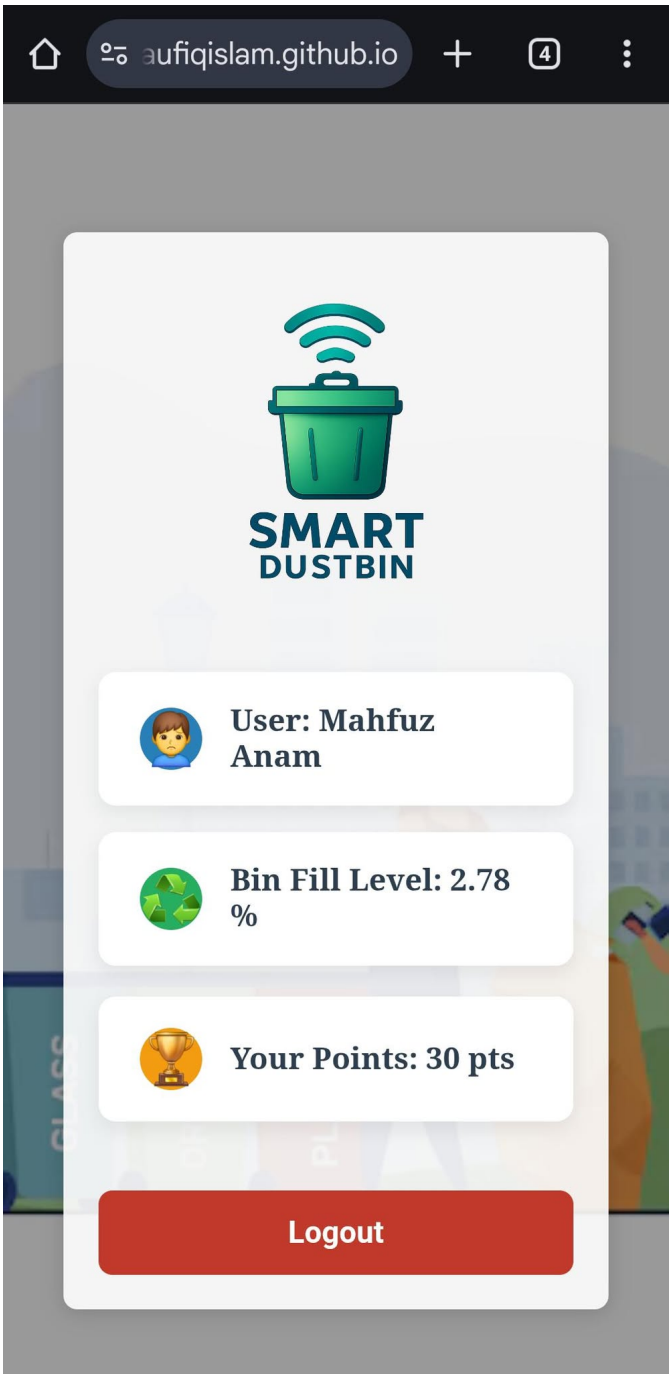

Figure 8.4: Dashboard

The consistency in design allows users to switch between web and mobile interfaces with ease, providing a familiar and intuitive experience across platforms.

9. Budget Estimation

The following table outlines the estimated cost for the electronic components required for one unit of the smart bin. Prices are approximate and based on commonly available components. This estimate does not include the cost of the bin structure, power supply, or assembly.

Component	**Quantity**	**Unit Price (Taka)**	**Total Price (Taka)**
ESP32 Microcontroller	1	1950	1950
Ultrasonic Sensor (HC-SR04)	2	100	200
RFID Reader (MFRC522)	1	220	220
Servo Motor (SG90)	1	150	150
RFID Cards	2	15	30
Miscellaneous (wires, enclosure, etc.)	1 set	150	150
Total			**2700**

Table 9.1: Estimated cost of electronic components per smart bin unit

Note: This cost estimation covers only the electronic components. Additional expenses such as bin fabrication, power supply units, and labor for assembly are not included and may vary depending on the scale of deployment.

10. Conclusion

The IoT-based smart waste management system with a reward mechanism offers an innovative solution to improve waste disposal practices. By combining automation, real-time monitoring, and user incentives, it enhances efficiency and engagement in waste management. The system's scalability and cost-effectiveness make it viable for broader implementation, potentially transforming municipal waste systems. Future enhancements could include integration with waste collection schedules and predictive analytics for maintenance.