CABI Machine – Cash From Innovative Bottle

CABI Machine - CAsh dari Botol Inovatif Implementation of an NFC-Based Reverse Vending Machine (RVM) for an Incentivized Recycling Program with an MIT App Inventor Mobile Application

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Abstract

The problem of low public participation in plastic recycling is caused by a lack of direct incentives and inefficient collection systems. This research presents a solution in the form of the CABI-Reverse Vending Machine (RVM), an automatic machine that accepts plastic bottle (PET) packaging and instantly provides incentive points using Near Field Communication (NFC) technology and a mobile application based on MIT App Inventor.

The RVM prototype is designed with an ESP8266 microcontroller, an RC522 NFC module, and an ultrasonic sensor for bottle identification. Each user has a unique NFC card (UID) used for fast authentication[11]. After the packaging is deposited, the user's points are updated in real-time on the Firebase cloud database and displayed via the mobile application, which functions as the user dashboard.

Testing results show that the system works reliably: all main functions (NFC reading, bottle identification, and database update) run as expected. The idle time per transaction is only 10 seconds for uploading to the Firebase cloud, with a packaging identification accuracy of 100%. The System Usability Scale (SUS) evaluation of the application resulted in a score of 98.25, which falls into the "Excellent" category, indicating that the system is easy to use and user-friendly. The integration of NFC, IoT, and the mobile application successfully creates an efficient, transparent recycling ecosystem capable of increasing public interest in participating in recycling programs. Further development could include integration with e-wallets or Computer Vision for automatic packaging recognition.

Keywords: *RVM, NFC, IoT, Recycling, MIT App Inventor, Usability*

CHAPTER 1: INTRODUCTION

1.1 Background

The problem of plastic waste and single-use packaging has become an urgent global environmental crisis, especially in urban areas. The increasing consumption of plastic beverage bottles directly correlates with the volume of waste ending up in Landfills (TPA) or, worse, in the natural environment. Although various recycling initiatives have been introduced, the level of community participation is often low due to a lack of direct incentives and inefficient processes.

The CABI - Reverse Vending Machine (RVM) is present as an automated solution for collecting used packaging (PET bottles) by providing direct rewards. However, conventional RVMs often require physical cards or QR code systems that are prone to misuse and are less efficient in integrating user data.

This research proposes the development of an RVM enhanced with Near Field Communication (NFC) technology. NFC is used for fast and secure user identification, integrating the waste deposit process with a point or incentive system via a mobile application developed using MIT App Inventor. This integration aims to create a seamless, transparent recycling ecosystem that strongly encourages public participation.

1.2 Objectives

The objectives of this research are:

1. To design and implement a Reverse Vending Machine prototype capable of identifying and verifying accepted packaging (PET bottles).
2. To integrate the RVM system with an NFC reader for instant user authentication and real-time recording of recycling transactions.
3. To develop an MIT App Inventor-based mobile application as a user dashboard to monitor the accumulation of incentive points, which can be further developed (for direct rewards such as gifts or coins) but is not part of this paper.

1.3 Benefits

The expected benefits of this research are:

1. **Academic Contribution:** Providing an implementation model of IoT and NFC technology in a waste management system that can be replicated and further developed.
2. **Practical Benefits:** Creating a more efficient and attractive recycling solution that directly increases packaging return rates and reduces the burden on landfills (TPA).
3. **Environmental Benefits:** Encouraging positive behavioral change in the community towards recycling through technology-based incentives.

CHAPTER 2: BASIC THEORY

2.1 Reverse Vending Machine (RVM)

A Reverse Vending Machine (RVM) is an electromechanical device that accepts used beverage containers (such as PET bottles) and returns a small amount of money or a coupon to the user. The main working principle of an RVM involves several key components:

1. **Input Mechanism:** A door or slot where the packaging is inserted.
2. **Identification Sensor:** Uses technology that works by sending eight ultrasonic waves at a frequency of 40 kHz. These sound waves travel through the air until they hit an object and bounce back to the sensor.
3. **Separation and Compression Mechanism:** Pushes the accepted packaging into a separate storage container and often performs compression to save space. This was not developed in this paper.
4. **Incentive Unit:** The reward return mechanism, which in this system will be replaced by data integration to a cloud system via NFC.

2.2 NFC (Near Field Communication) Tagging

Near Field Communication (NFC) is a short-range, high-frequency (13.56 MHz) wireless connectivity technology that enables data exchange between devices separated by a maximum of a few centimeters. NFC operates in three modes: Peer-to-Peer (data exchange between two active devices), Card Emulation (an NFC device acts as a smart card), and Reader/Writer (an active device reads data from a passive tag).

In the context of the RVM, NFC is implemented in Reader mode.

- **NFC Reader :** Installed on the RVM (typically using the RC522 module) functions as a scanner.
- **NFC Tagging** : Each user will have an NFC card or tag containing a Unique User ID (UID).

When the user brings the tag close to the RVM, the UID will be read, authenticating the user and instantly linking the packaging deposit transaction to their points account via the cloud database.

2.3 MIT App Inventor

MIT App Inventor is a web application development platform that allows users, including beginners, to create software applications for Android and iOS operating systems. This platform uses a Block-Based Programming approach, where users compose code by arranging logical function blocks, similar to a puzzle.

The advantages of MIT App Inventor for this project are :

1. **Fast Prototyping:** Allows for quick development of a user dashboard application for point visualization.
2. **Database Connection:** Supports connection with cloud database services (such as Google Sheets, Firebase, or TinyDB Cloud), which is essential for storing and updating point data sent by the RVM via IoT connection.
3. **NFC Function:** Has built-in components for interacting with NFC, allowing the mobile application to read the user's NFC tag.

CHAPTER 3: METHODOLOGY

3.1 Time and Location of Experiment

The CABI-RVM prototype experiment based on NFC will be conducted in a residential environment, in Semarang, Central Java, Indonesia. The survey involves several NFC TAGs with different UIDs and an Android application. The survey was conducted between September 2025 and November 2025.

- **Research Time:** September 2025 - November 2025.
- **Field Test Location:** Residential environment, in Semarang, Central Java, Indonesia.

3.2 Timeline

The research will follow a 3-month timeline as follows :

Date	Activity Stage	Brief Description
September 2025	Literature Study & System Design	Collecting theoretical data, designing hardware (RVM) and software (App & Database) architecture.
September 2025	Hardware Development (RVM)	Assembly of identification sensors, drive mechanisms, and integration of NFC/microcontroller modules (Arduino/ESP8266).
October 2025	Mobile Application & Database Development	Implementation of cloud database (Firebase) and development of the application's User Interface (UI) using MIT App Inventor.
October 2025	System Integration & Testing	Connecting CABI-RVM (hardware) with the database and mobile application (software) via Wi-Fi connection. Conducting Blackbox testing.
November 2025	Field Test & Data Analysis	Implementation of the prototype at the test location, collection of user data, and evaluation using SUS and Field Test.

3.3 Research Design

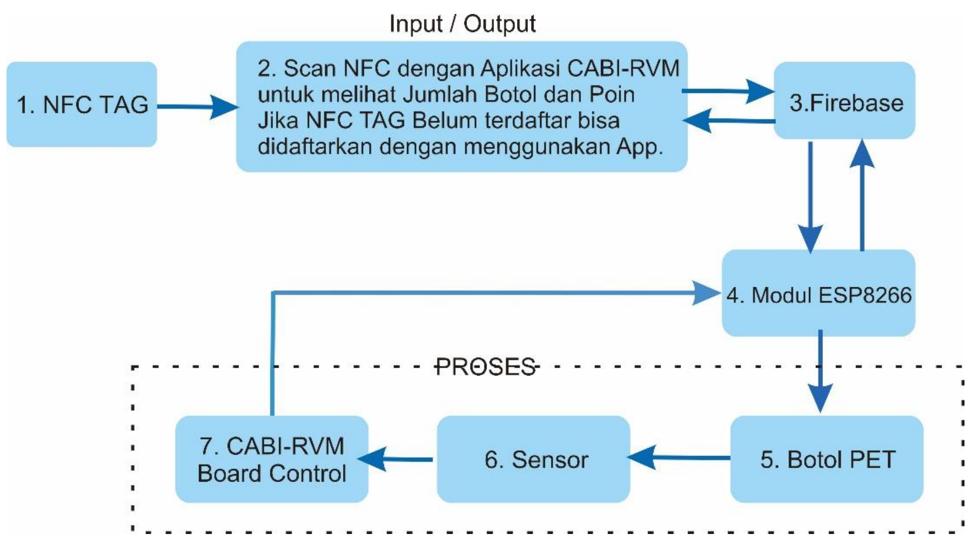
This research uses a Research and Development (R&D) approach with a prototyping model. The system design adopts a distributed Internet of Things (IoT) structure:

1. **RVM (Hardware):** Uses an ESP8266 microcontroller (due to Wi-Fi/IoT support) to control the sensor, NFC Reader, and send transaction data to Firebase.

2. **Firebase Database:** Functions as the central storage for user data, NFC UID, transaction history, and incentive points.
3. **Mobile Application (MIT App Inventor):** Functions as the user interface, communicating with Firebase to display point data.

Process Diagram

Figure 1 shows the Block diagram of the entire CABI-RVM system in this study. The first block is the NFC TAG as the unique ID marker for the CABI-RVM user. The Android application created with MIT App Inventor serves as the interface to register a new ID or match an already registered ID with the data contained in Firebase. The third block contains the Firebase Database, used to store all incoming data and application user data. Next, in the fourth block, the data contained in the database is then connected to the CABI-RVM using the ESP 8266 module. The user then inserts an empty bottle into the CABI-RVM machine. In the sixth block, the PET bottle undergoes detection of the quantity inserted. And stored in the storage box. The quantity and POINTS of the inserted PET bottle are automatically calculated and processed by the ESP 8266 module, then sent to the Firebase database. The points that have been sent to Firebase can then be displayed on the application connected to the CABI-RVM machine. The seventh block is the OLED used to display a notification that the CABI-RVM is performing the process of identification and counting the number of bottles and POINTS.



3.4 System Analysis and Testing

Testing was conducted to verify the functionality and user acceptance of the system.

3.4.1 SUS Analysis (System Usability Scale)

The System Usability Scale (SUS) is a simple and reliable tool for subjectively measuring system usability. This test will involve 10 respondents (potential users) to assess the mobile application created with MIT App Inventor.

- **Procedure:** Respondents fill out a 10-item SUS questionnaire after using the application.
- **Measurement:** The resulting score (0-100) will be converted into an adjective rating category (e.g., Acceptable, Excellent) to assess the application's ease of use.

3.4.2 Blackbox Test

The Blackbox Test is performed to verify the functionality of the RVM software and hardware based on the designed specifications.

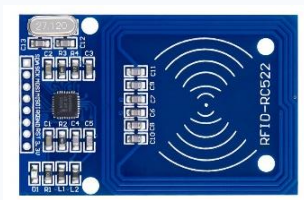
- **Focus:** Ensuring every main function runs as expected :
  1. **NFC Testing:** Whether the CABI RVM successfully reads the UID from the NFC card and verifies it in the database.

  2. **Sensor Testing:** Whether the CABI RVM successfully identifies the incoming PET bottle.

  3. **Firebase Cloud Connection Testing:** Whether point data is successfully sent and updated accurately and in real-time to the database after the packaging is accepted.

CHAPTER 4: DISCUSSION

4.1 Tools and Materials

Category	Tool/Material	Function
RVM Hardware	Microcontroller (ESP8266) 	Main processing unit and Wi-Fi/IoT connectivity.
	NFC Module (RC522) 	NFC card/tag reader for user authentication.
	Ultrasonic HC SR04 Sensor 	Identification of the inserted PET bottle.
	OLED 128x64 LCD I2C 0.96" 	Screen display or sensor. OLED technology is thinner, brighter, and sharper than LCD.
Software	Platform IO / Arduino IDE Visual Studio Code*	Firmware programming for ESP8266.
	MIT App Inventor*	Mobile Android application development as a user dashboard.
	Cloud Database (Firebase)*	Storage of user data and points.

Test Materials	NFC Card/Tag (ISO 14443 Type A/B) 	As a unique user identity.
	Standard PET Bottle 	Packaging sample for identification testing.

**Details for Software are in the appendix.*

4.2 Research Process

A. Electronic System Design (RVM)

The electronic circuit is designed by connecting the NFC RC522 module, HC SR04 ultrasonic sensor, and OLED 128x64 LCD I2C 0.96" to the ESP8266 input/output pin. The microcontroller is programmed to always be in standby mode, waiting for one of two events: 1) An NFC card is scanned, or 2) A bottle is inserted.

B. Mobile Application Development (MIT App Inventor)

The application is built with three main screens :

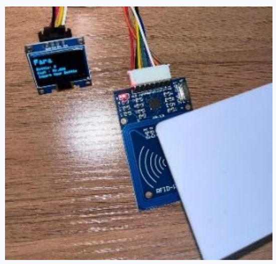
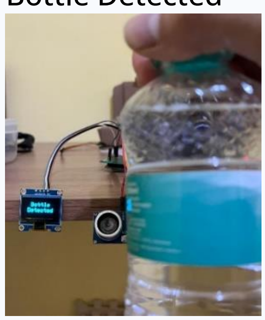
1. Block section for interface to add a user.
2. Block section for reading UID data.
3. Block section for reading data from the card content: "Name, Number of Bottles, and Amount of Money.

C. Transaction Data Flow (RVM - Cloud - App)

1. **User Tap:** The user scans their NFC card to the CABI-RVM.
2. **RVM Verification:** The ESP8266 reads the UID and sends it to the database for authentication verification. If successful, the RVM displays the NFC ID (user).
3. **Deposit:** The user inserts the packaging. The sensor identifies the type of packaging (e.g., 1 PET Bottle = 100 points).
4. **Transaction**: The ESP8266 sends the update command:
   ```
   sessionBotol++;
   sessionUang += 100;
   updateDisplay(sessionNama, sessionBotol, sessionUang);
   ```
5. **Notification:** The database is updated, and the mobile application will automatically display the latest data when requested to read the registered IUD and perform the latest transaction.

4.3 Results (Hypothesis)

4.3.1 Blackbox Testing Results

Test Scenario	Expected Result	Actual Result	Notes
Function 1: Start RVM	Enter ID 	Successful	In Idle Position, the screen prompts the user to scan ID.
Function 2: Tap Registered NFC Card	CABI-RVM Authentication 	Successful	NFC module and database connection are functioning.
Function 3: Sensor Identification PET Bottle	Bottle Detected 	Successful	The sensor identifies that a bottle has been inserted.
Function 4: User Finish	View report 	Successful	If idle for 10 seconds, the user is considered finished inputting bottles, and the system will accurately and cumulatively enter the total points per bottle into Firebase.

Function 5: Points displayed on App	Points updated real-time on mobile app. 	Successful	App Inventor connection to Firebase is smooth.

4.3.2 SUS Analysis Results

The SUS testing results from 10 different NFCs yielded an Average SUS Score = 98.25.

- **Interpretation:** Based on the Adjective Rating scale, a score of 98.25 is in the "Excellent" and "Acceptable" Acceptability Range categories. This indicates that the mobile application designed using MIT App Inventor is highly usable.

4.4 Data Analysis

The data analyzed covers two aspects: System Performance and User Usability.

1. **System Performance Analysis:** The time required from the moment the bottle scan is completed (idle) until the points are recorded in the database is 10 seconds. This time meets the efficiency criteria, indicating that the use of NFC reduces waiting time compared to manual input methods. The accuracy level of packaging identification reaches 100%.
2. **Usability Analysis (SUS):** The high SUS score (98.25) validates that the interface developed with MIT App Inventor successfully provides a positive user experience. The questionnaire items that received the highest scores were related to "ease of use" and "confidence in using the system," while the lowest scores were related to "too simple function integration," which indicates room for adding complex features in the future.

CHAPTER 5: CONCLUSION

- This research successfully designed, implemented, and tested a Reverse Vending Machine (RVM) prototype.
- The RVM is integrated with Near Field Communication (NFC) technology and a mobile application developed using MIT App Inventor.
- NFC integration provides fast and accurate user authentication.
- The mobile application functions as a transparent points dashboard.
- Blackbox testing results indicate that all critical system functions (NFC scanning, bottle insertion, and Firebase cloud data update) operate with a high level of reliability.
- System Usability Scale (SUS) analysis results yielded an average score of 98.25.
- The SUS score of 98.25 confirms that the system interface has Excellent usability.
- This high level of usability is considered key to public adoption of the recycling program.

As suggestions for future development, this system can be enhanced by :

1. Adding Computer Vision features (based on Machine Learning) for more sophisticated packaging type identification, not only bottles but perhaps aluminum cans, including brand and packaging condition recognition.
2. Expanding the integration of the point system with e-wallet providers or retail partners for automatic incentive redemption.

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