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# Development of a PET Bottle Collection System for a Green Campus Community

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KEYWORDS

Green Campus
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ABSTRACT

Waste recycling is an essential component of achieving a Green Campus community, and plastic bottle recycling is one method for promoting recycling that also has significant environmental benefits. The researchers created a PET Bottle Collection System, which includes a Reverse Vending Machine (RVM) prototype and a cross-platform mobile monitoring application, to promote recycling and proper waste disposal at Iloilo State College of Fisheries and to support the college's initiative to become a Green Campus community. The RVM could detect plastic and non-plastic bottles using a capacitive proximity sensor and a photoelectric sensor and dispense a one-peso coin for every four plastic bottles accepted. The machine also used a Raspberry Pi 3 Model B+ as its central control unit, an MCP3008 ADC IC to read the analog signals from the sensors, and an infrared sensor to detect whether the machine's storage capacity is full and ready for extraction. The cross-platform mobile application was created with the React Native framework to monitor the number of coins remaining to be dispensed in the machine, the number of Plastic Bottles accumulated, and the status of the RVM, whether it is already full or not. The system was tested and evaluated for functionality, accuracy, efficiency, and response time, and the results showed that the system met the intended design criteria. Further improvements to the system were recommended in order for it to be implemented in a larger environment.

## 1.0 INTRODUCTION

Waste recycling is an essential aspect of achieving a Green Campus community. A Green Campus is a higher education community that promotes energy efficiency, resource conservation, and environmental quality by creating a healthier living and learning environment and educating sustainability [1]. In 2010, Universitas Indonesia (UI) launched world university rankings, later renamed UI GreenMetric World University Rankings, to measure campus sustainability efforts [2-4]. Moreover, as of 2020, 912 universities from 84 countries participated in this program [5], with only six from the Philippines [6]. The UI GreenMetric established performance evaluation criteria

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and methodology, with waste treatment and recycling activities as one of the primary criteria, and its indicators include recycling programs, toxic waste recycling, organic waste treatment, inorganic waste treatment, sewerage disposal, and a campus policy to reduce the use of paper and plastic [7-9].

Recycling has become increasingly important in recent years, as plastic waste has become a massive problem both on land and at sea [10]. It is estimated that only 9% of all plastic ever produced has been recycled, while only 12% has been incinerated, with the remainder ending up in soils, oceans, and landfills [11]. Polyethylene Terephthalate (PET) is a synthetic resin produced by the polymerization of ethylene glycol and terephthalic acid [12]. PET is a clear and lightweight plastic widely used in packaging foods and beverages, particularly convenience-sized soft drinks, juices, and water [13]. One of the most common recyclable plastic wastes is PET bottles; this waste is recycled into bottles, packaging materials, stationery, and daily necessities, among other things [14]. Recycling plastic bottles has significant environmental benefits, such as lower greenhouse gas emissions and consumption of fossil resources [15, 16].

Dumpayan et al. [17] developed a Reverse Vending Machine (RVM) that converts "plastic" bottles into credits that can be used to purchase various items from the vending machine. Solar or a commercial source powers the machine. The RVM designed by the researchers was comprised of three major components: the vending machine, the bottle acceptor unit, and the control center. Photoelectric and capacitive sensors were used to detect clear PET bottles. To determine the accuracy of these aspects, the researchers conducted experiments on each component of the RVM. It has demonstrated high accuracy in recognizing RFID accounts, distinguishing between plastic and non-plastic bottles, storing or updating points for each account, and distributing products.

Gaur et al. [18] proposed a simple approach to designing a Reverse Vending Machine (RVM). Their proposed system is based on fraud detection sensors that begin working after the plastic material is inserted into it and checked by a series of sensors. This system used a Strain Gauge Weight Sensor, Capacitive Proximity Sensors, and an Infrared Photoelectric Sensor to detect fraud. RVM accepts plastic items and rewards them with coins based on the weight of the plastic items. This system is implemented using Xilinx in Verilog.

Karin et al. [19] proposed a system that demonstrates the use of a Field Programmable Gate Array(FGPA) to implement a Bottle Recycle Machine. This system allows users to recycle plastic bottles while earning reward points. FPGA is used in this case because hardware-based implementation on an FPGA is typically much faster than software-based implementation on a microcontroller. In addition, an ultrasonic sensor is used in the design to recognize different bottle sizes, which is used to calculate the cash reward. This system was built with Verilog HDL on an Altera DE2-115 board.

Rubio and Lazaro [20] developed a Solar Powered Reverse Trash Vendo Machine (SPRTVM) intending to reduce the practice of improper waste management by providing rewards for proper waste disposal. The device can detect whether the scanned material is a plastic bottle or an aluminum can, each with its monetary compensation value. Furthermore, the device's owner can check the status of the coin dispenser and bins via an Android messaging app, and when the coin dispenser or trash bins reach a specific limit, an automatic text message notification is sent to the owner.

The researchers aim to develop a PET bottle collection system that includes a Reverse Vending Machine (RVM) prototype and a cross-platform mobile monitoring application to encourage recycling activity and proper waste disposal at Iloilo State College of Fisheries. In addition, this project further aims to support the initiative of ISCOF to become a Green Campus community.

Specifically, this research aims to:

1. Construct a Reverse Vending Machine that can reward a one-peso coin for every four PET bottles dropped into the proposed machine, using the Raspberry Pi 3 Model B+ as the central control unit, photoelectric and capacitive proximity sensors to detect PET bottles, an MCP3008 ADC IC to read the analog signals from the sensors, and an infrared sensor to determine whether the RVM is already full or not.
2. Develop a mobile application using the React Native Framework to monitor the number of coins remaining to be dispensed in the machine, the number of PET Bottles accumulated, and the status of the RVM, whether it is already full or not.
3. Test and Evaluate the Functionality, Accuracy and Efficiency, and Response Time of the system.

## 2.0 METHODOLOGY

### SYSTEM DESIGN

*A. Design Criteria*

The proposed reverse vending machine design is based on the following criteria:

1. Functionality: The machine must be able to function correctly and execute the process operation without errors, beginning with the detection of PET bottles, counting the PET bottles, dispensing coins for rewards, and sending a notification to the authorized personnel via the mobile app that the system is already full.
2. Accuracy and Efficiency: The machine must be able to distinguish between PET bottles and other materials and reject non- PET bottles. The counting of PET bottles and coin dispensing must also be correct, with one peso coin dispensed for every four PET bottles. The number of errors in all of these operations should be maintained to a minimal level.
3. Response Time: The machine must be able to quickly complete operations and update the system's status to the mobile application.

*B. Flowchart Diagram*

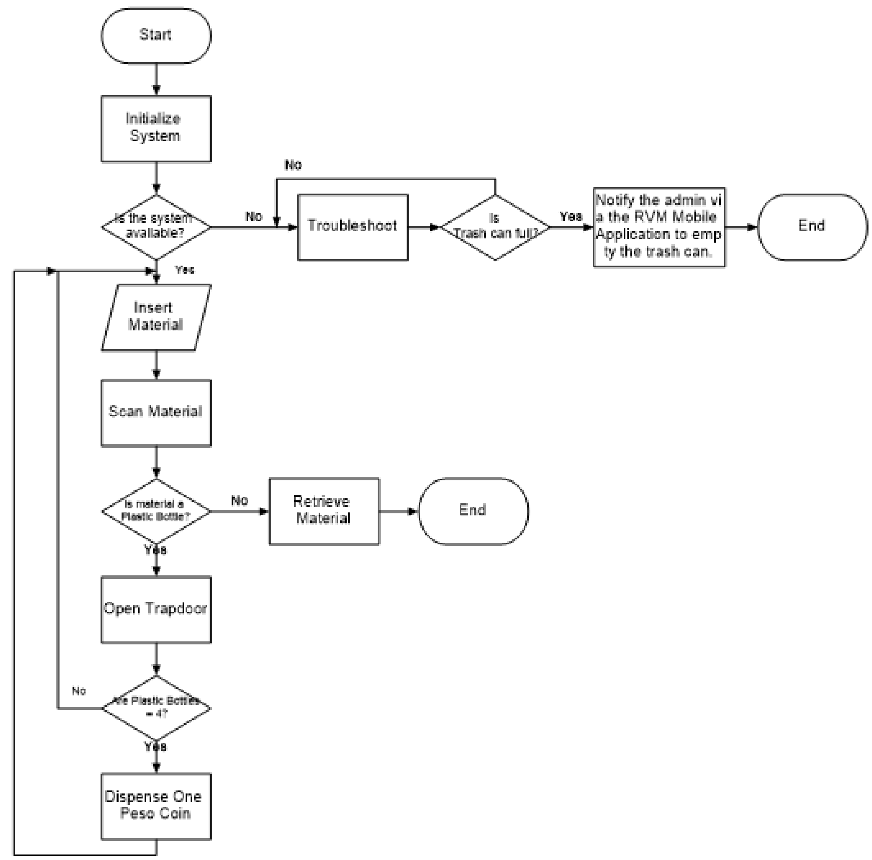



Figure 1. System Flowchart

Figure 1 illustrates the flowchart of the system. The system is first initialized by checking its availability; if it is unavailable, it will troubleshoot whether the trash can is already full and display the status of the RVM in the mobile application for the authorized personnel to take action. The infrared sensor is used to detect and measure the level of the bin. If the system is operational, it will scan the inserted material to determine whether it is a PET bottle. The PET bottle will be verified using the capacitive proximity sensor and photo-electric sensor.

If the machine recognizes the material as a PET bottle, it will accept it by opening the trapdoor. In order for the machine to dispense a one peso coin, four PET bottles must be accepted. If the material is invalid or is not accepted as a PET bottle, the trapdoor will not open, and the user must retrieve his or her material.

*C. RVM Hardware Components*

The hardware part includes the Raspberry Pi 3 Model B+, MCP3008 ADC IC, photoelectric sensor, capacitive proximity sensor, infrared sensor, servo motor, and power supply.

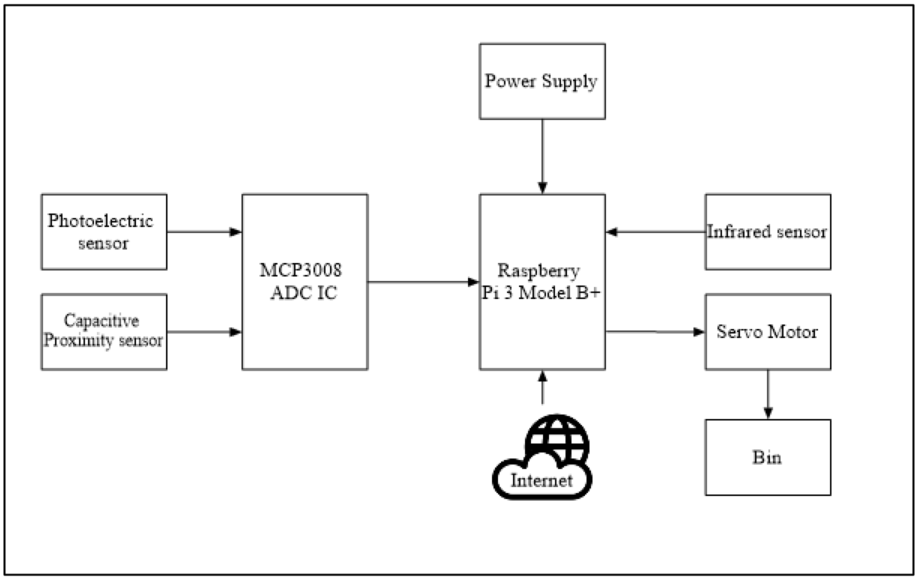



Figure 2. System Block Diagram

Figure 2 shows the block diagram of the system. To function, the Raspberry Pi 3 Model B+ must be connected to an external power supply. The photoelectric and capacitive proximity sensors communicate directly with the MCP3008 ADC IC, which reads the analog signals from the sensors and sends them to the Raspberry Pi, the system's central control unit. The photoelectric sensor can detect clear PET bottles, whereas the capacitive sensor cannot. When the capacitive proximity sensor detects the material, it is determined that it is not a PET bottle; when it does not detect, and the photoelectric sensor detects, it is determined to be a PET bottle [17]. Photoelectric sensors are preferable for detecting clear bottles because they detect transparent materials and operate over longer distances, even in low light [21]. The infrared sensor communicates directly with the microprocessor; this sensor determines whether the Recyclable Vendo Machine is full and ready for extraction. The actuator is the servo motor, which operates when the machine accepts the PET bottle that the photoelectric and capacitive proximity sensors have scanned. The Raspberry Pi must be connected to the internet to update and display the system's status in the RVM mobile app, such as the bin is already full.

*D. RVM Mobile Application*

The React Native framework was chosen as the platform for the application's development primarily because it supports cross-platform mobile development, allowing developers to create an app for multiple platforms (e.g., Android, iOS) with a single codebase [22]. Visual Studio Code was used as the Integrated Development Environment (IDE) with Javascript as the programming language, and Firebase Realtime Database was used for data storage, a feature offered by Firebase Cloud Server. The mobile app displays the number of bottles collected, the remaining coins that have yet to be dispensed, and the storage capacity status of the RVM.

## IMPLEMENTATION

Reverse Vending Machine Prototype

*Figure 3. Reverse Vending Machine Prototype*

Figure 3 shows the top view of the prototype of the Reverse Vending Machine. This prototype was built with a plastic garbage bin due to its low cost and convenience of use.

*Figure 4. Reverse Vending Machine Top View*

Figure 4 shows the top view of the prototype, which shows the Raspberry Pi connected to the power supply, Local Area Network via the LAN cable, and the MCP3008 ADC IC, which reads analog signals from the sensors then sends them to the Raspberry Pi. It also shows the coin dispenser, coin hopper, and PVC pipe into which the user can insert their PET bottle.

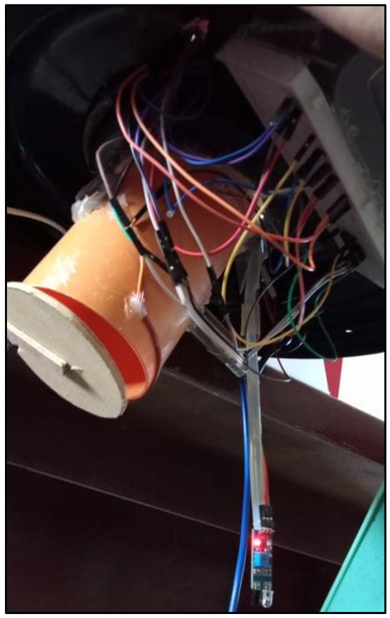


*Figure 5. Reverse Vending Machine Bottom View*

Figure 5 shows the bottom view of the prototype, which depicts the device's circuit connection, that involves the connection of the sensors (capacitive proximity and photoelectric sensors) to the servo motor, which would open the trapdoor if the inserted PET bottle is accepted, and the infrared sensor, which would send a signal to the control unit indicating that the device is already full.

*RVM Mobile Monitoring App*

The RVM Mobile App is intended for use by the authorized personnel to monitor the number of remaining coins to be dispensed in the system, the number of accumulated PET Bottles, and the status of the RVM, whether it is already full or not. This mobile app does not affect the hardware component of the system.

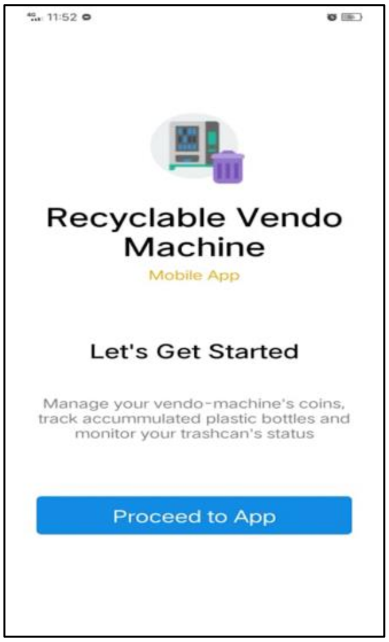



*Figure 4. Launch screen*

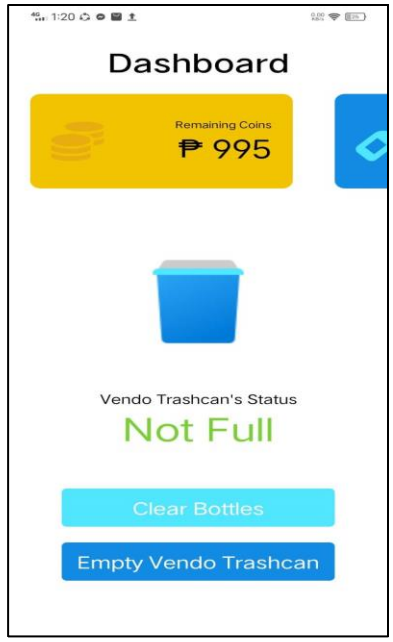



*Figure 5. Dashboard section showing the Remaining Coins*

Figure 4 shows the Launch screen; when the 'Proceed to App' button is pressed, the Dashboard is displayed. Figure 5 shows the section of the Dashboard that displays the remaining coins that can still be dispensed. The authorized personnel determines the total number of coins directly in the database. Moreover, the authorized personnel can enter the coins he wants to dispense, and the coins already dispensed will be deducted from the initial inputted value, which is displayed in the upper part of the Dashboard.


*Figure 6. Dashboard section showing the trash can is not full*

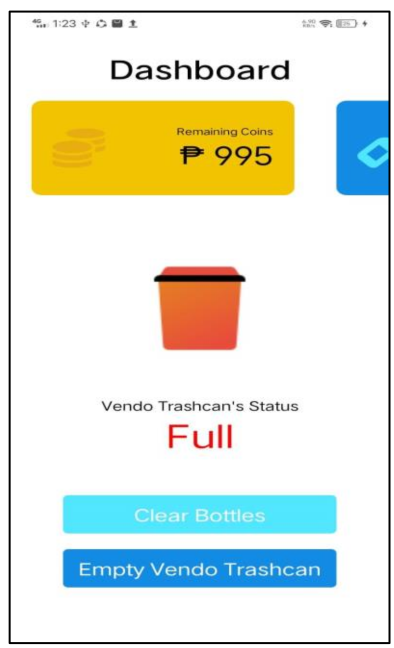
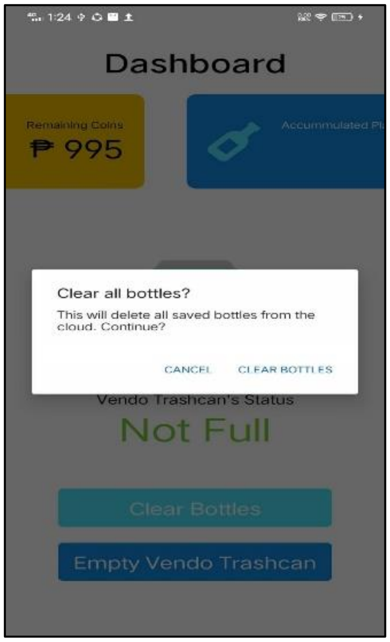



*Figure 7. Dashboard section showing the trash can is full*

Figure 6 depicts the Dashboard section displaying Accumulated Bottles in the RVM, located in the upper portion of the Dashboard. The Dashboard also shows the RVM's status, such as whether it is already full or not. If the RVM is not full, the icon will be blue with the label 'Not Full' (Figure 6); otherwise, it will be red with the label 'Full' (Figure 7). *Clear Bottles* and *Empty Vendo Trashcan* are also options on the Dashboard.



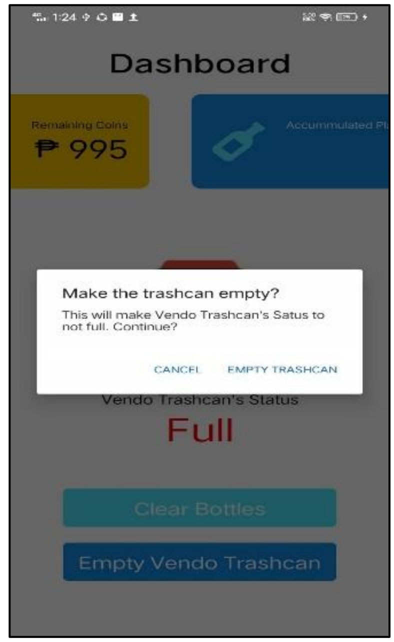




*Figure 8. Alert Message('Clear Bottles' option is pressed)* *Figure 9. Alert Message ('Empty Vendo Trashcan' option is pressed)*

Figures 8-9 depict the alert messages displayed when the user clicks the Clear Bottles and Empty Vendo Trashcan buttons. When the user pressed the *Clear Bottles* option, the status of the Accumulated Bottles is reset, and the number displayed returns to zero. When the user pressed the *Empty Trashcan* option, the trashcan status returns to 'Not Full,' indicating that the bottles in the RVM were already extracted and that there is available space in the RVM's storage area.

## TESTING AND EVALUATION

Testing and evaluation were conducted to test the system's functionality, accuracy and efficiency, and response time. The following test cases were conducted:

1. Testing the accuracy and efficiency of the system. This testing consists of three subtests: (a) the accuracy of the sensors in determining the type of material inputted into the system, (b) the accuracy of counting PET bottles, (c) the accuracy of dispensing one peso coin for every four PET bottles accepted into the system, and (d) detecting full storage level capacity and notifying the authorized personnel via the mobile app that the system is already full.
2. Testing the response time of the hardware, and response time between the mobile application and the hardware system. This testing consists of two subtests: (a) the hardware's response time to accept PET bottles, and (b) the timing of communication between the hardware and the mobile application to update the app with the number of accumulated bottles.

## 3.0 RESULTS AND DISCUSSION

Table 1 shows the final accuracy and efficiency test results, which show that PET bottles can be distinguished from other materials with 100% accuracy and that other materials cannot be accepted if they are not PET bottles. The accuracy of counting PET bottles, dispensing a coin for every four PET bottles accepted, and sending a notification to the mobile app when the system is already full were also tested, and it passed the required accuracy level. These results indicate that the sensors in this system are accurate, and the system has been proven efficient.

Table 1. Final Test Results from material sensing

| Test | PET bottle | Glass | Paper Material (e.g., Paper Cups) | Tin Cans |
|---|---|---|---|---|
| 1 | ✓ | ✕ | ✕ | ✕ |
| 2 | ✓ | ✕ | ✕ | ✕ |
| 3 | ✓ | ✕ | ✕ | ✕ |
| 4 | ✓ | ✕ | ✕ | ✕ |

Accepted (✓) Rejected (✕)

Table 2 shows that the system can accept valid PET bottles in under a minute and that there are few to no delays in updating the number of accumulated PET bottles from the machine to the mobile app. When these operations are combined, the total average response time is less than a minute, which is ideal. However, since the system requires an internet connection to update the number of accumulated PET bottles to the mobile app, it should be connected to a fast and reliable internet connection.

Table 2. Response Time of System Operation

| Test | Bottle Acceptance | Updating of the number of accumulated P.B. from RVM to Mobile App | Total Response Time |
|---|---|---|---|
| 1 | 10.06 sec | 2.31 sec | 12.37 sec |
| 2 | 16.24 sec | 2.14 sec | 18.38 sec |
| 3 | 14.03 sec | 2.43 sec | 16.46 sec |
| 4 | 11.21 sec | 2.26 sec | 13.47 sec |
| Ave. time | 12.89 sec | 2.29 sec | 15.17 sec |

## 4.0 CONCLUSION

Recycling plastic waste has significant environmental benefits and is an essential component of achieving a Green Campus community. A PET Bottle Collection System was developed to encourage recycling and proper waste disposal at Iloilo State College of Fisheries and support the college's initiative to become a Green Campus community. The system is composed of the Reverse Vending Machine (RVM) prototype and a cross-platform mobile monitoring application. The RVM can detect and accept PET bottles while rejecting non-PET bottles and rewards a one-peso coin for every four PET bottles accepted in the system. A mobile application was also developed to monitor the number of coins remaining to be dispensed in the machine, the number of PET Bottles accumulated, and the status of the RVM, whether it is already full or not. The system was tested and evaluated based on its functionality, accuracy, efficiency, and response time, and the results demonstrated that the system met the intended design criteria. Overall, the researchers successfully developed an efficient PET Bottle Collection System that could be used for the ISCOF system.

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