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Plastic2Fantastic: Reverse Vending Machine for Plastic Bottles

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RESEARCH ARTICLE INFORMATION

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ABSTRACT

Waste has become one of the most serious global issues today. Recycling is one of the important ways to manage waste properly. Reverse Vending Machine is an innovative idea that inculcates the habit of recycling waste materials. To overcome the problem of waste, Plastic2Fantastic: Reverse Vending Machine for Plastic Bottles was developed as a machine that accepts and deposits empty plastic beverage containers in exchange for money. The machine was constructed from aluminum and implemented in a standard trash bin equipped with Raspberry Pi 3B, 7-inch Touch Screen LCD, RFID reader, coin hopper, ultrasonic sensor, capacitive proximity sensor, inductive proximity sensor, IR proximity sensor, and M995sg servo motor. The machine is capable of detecting RFID cards, identifying plastic bottles as deposits, and dispensing coins. Functionality testing showed very good performance, with the recommendation that labels be added for improved user guidance. Evaluation results indicated that respondents strongly agreed with the machine's usefulness, demonstrating its potential impact in promoting recycling practices. The positive feedback highlights the machine's effectiveness and user-friendliness. The machine as a whole offers a cost-effective and simple solution to the waste problem.

Keywords: *Reversed Vending Machine, Raspberry Pi 3B, waste management, recycling, plastic bottles*

Introduction

Nowadays, one of the dominant problems in the world is improper waste disposal. Mawis (2019) stated that the Philippines generates more solid waste as the population increases, living standards are enhanced, and urban and rural areas are being developed. According to a report by the Senate Economic Planning Office (SEPO), the country's waste generation steadily increased from 37,427.46 tons per day in 2012 to 40,087.45 tons in 2016.

Plastic waste is one of the major pollutants among the various contaminants that are disposed in the environment. Data from the study of Tantiangco (2018) showed that the Philippines wastes 6,237,653 kg (6875.84 tons) of plastic per day, of which 81% is mismanaged. Similarly, Dela Cruz (2023) stated that based on the 2021 report of the World Bank Organization, the Philippines generates 2.7 million tons of plastic waste annually (Dela Cruz, 2023). Plastic bottles are one of these, wherein 1.5 million of which are being disposed and scattered in landfills and coastline as stated by WWF (2018). According to the Ecosystems Research and Development Bureau of the Department of Environment and Natural Resources (DENR), plastic bottles and bottle caps rank as the third and fourth most collected plastic trash items in the annual Coastal Cleanup Day in more than 100 countries (Dela Cruz, 2023). Plastic bottles are mostly used, the daily consumption is continuously increasing and it is harming the environment. The problem now is that plastics are scattered all over the place especially those plastic bottles that do not decay.

People tend to overlook the reality that most waste materials that are being thrown are recyclable, plastic bottles are an example. Through the method of recycling, people can make use of these things seen as waste into something beneficial. There are many ways to recycle those plastics. According to Rinkesh (2019), the waste hierarchy consists of 3Rs: reduce, reuse, and recycle. This waste hierarchy should serve as guidance for creating a sustainable life and these principles should be incorporated in the daily lives of the people.

However, the problem lies with the people who are not keen and ignorant about recycling. In the Philippines, for instance, only scavengers collecting plastic bottles are the ones who take part in the process of recycling. They are the first-hand movers in the process of recycling plastic bottles but sometimes, they are not doing it out of love for nature but only to earn and make a living for themselves and their families. To protect the environment and save energy, one has to recycle used and empty plastic bottles.

At present, several municipalities have waste management policies. The Local Government Units (LGUs) are implementing the Republic Act 9003, known as the Ecological Solid Waste Management Act of 2000, to ensure the protection of the public health and environment. The law requires that there should be proper waste segregation, reduction, reuse, and recycling. However, despite the existence of this Waste Management Act, most of the people in the community are not aware of it and do not practice proper waste segregation and disposal. Ibañez (2021) noted that waste management responsibilities have been unfairly placed on local government units (LGUs), which often lack the necessary resources, thereby leading to poor implementation of RA 9003, according to the report by the Philippine Institute for Development Studies (PIDS). The present recycling practice of some in which people need to bring the waste in bulk to the recycling center might bother them and become a discouraging factor for them to recycle. This results in low recycling efforts and high plastic pollution that contributes to the major problem of the country.

In response to the growing problem of the community and the Philippines as a whole, the Plastic2Fantastic: reversed vending machine for plastic bottles was developed. It is a machine that accepts and deposits used empty plastic beverage containers in exchange for money which can be withdrawn using the RFID card. This machine can convince the consumer to store and deposit their plastic bottles of drinks and beverages instead of throwing them elsewhere. This likewise provides a great incentive for people to take an interest in the process of recycling. This machine will be the first of its kind in the region. This initiative does not have much effect on waste volumes but this project hopefully encourages people to change their habit of throwing plastic bottles that can still be recycled. When this is sustained, this could give substantial significance to waste management globally, encompassing environmental, economic, and social dimensions. Its environmental impact will be the reduction in plastic pollution. Economically, the RVM would provide financial incentives for individuals to recycle, potentially increasing recycling rates, and this may lead to cost savings for municipalities as the volume of waste requiring disposal would be reduced. As to its social impact, the RVM may also promote community involvement in waste management, fostering a sense of collective responsibility for the environment

The study generally aimed to develop a reversed vending machine for plastic bottles to help encourage people to recycle. Specifically, it aimed to develop a machine that is capable of detecting RFID cards, plastic bottles as deposit, weight and cash computation, and coin dispensing; and evaluate the user acceptance of the machine.

Methods

Population and Locale of the Study

The population of the study was the residents of Barangay Anao, Cabagan, Isabela. The evaluation of user acceptance involved a sample of the residents particularly those who had registered their RFID and used the machine. There were 30 users who were randomly selected as respondents. The machine was deployed for operation testing and evaluation at Barangay Anao, Cabagan, Isabela.

Data Gathering Procedures

A review of related literature was conducted to gather theoretical and conceptual data for the study. Relevant studies were likewise gathered to supplement the design concepts and ideas on hand.

Evaluation of user acceptance was carried out through a survey. Hence, a questionnaire was prepared for this purpose. The existing user acceptance frameworks were reviewed and adapted for the questionnaire. The questionnaires were prepared and distributed to the respondents after using the machine. Data gathered from the respondents were tallied and analyzed using the appropriate statistical tools.

Data Analysis and Statistical Tools

Data gathered from the questionnaires were tallied and analyzed using frequency count and weighted mean. To interpret the mean rating evaluation on user acceptance, the Likert Scale was used as shown in Table 1.

Table 1. The Likert Scale

Scale	Statistical Limits	Descriptive Value
5	4.21 – 5.0	Strongly Agree
4	3.41 – 4.20	Agree
3	2.61 – 3.40	Undecided
2	1.81 – 2.60	Disagree
1	1.0 – 1.80	Strongly Disagree

Design Procedures

This portion presents the design procedures that served as the basis and guidelines in the development of the project. Specifically, the CDIO (Conceive, Design, Implement, Operate) design framework was utilized.

Phase I. Project Conceptualization

With the increasing emphasis in recent years on environmental protection, the recycling of used beverage containers and other similar commodities has become an important factor in the conservation effort. More specifically, the recycling of plastic containers has proven to be environmentally beneficial. This has led to the concept of developing a mechanism to help the community at Barangay Anao in its waste management initiatives especially that the Barangay is currently determined to strictly implement environmental policies. Brainstorming was conducted to come up with candidate solutions to the problem of waste management.

The most feasible solution was then selected. Hence, the study entitled "Plastic2Fantastic: Reversed Vending Machine for Plastic Bottles" was conceptualized. The study aimed to develop a machine that can collect recyclable plastic bottles and provide cash incentives in exchange for the valuable effort to help the community in recycling.

Phase II. Project Design

This phase focused on the technical part of the project. In this phase, the initial design and layout were prepared. Components required in the project were identified and requirements were specified. Figure 1 presents the initial block diagram of the machine in which the RFID card is recognized using an RFID reader and serves as the initialization of the machine. The touchscreen monitor serves as a display and the control key where you can find the register, deposit, and withdrawal functions. Plastic bottle functions as an input to be sensed by the capacitive, inductive, and infrared proximity sensor. Specifically, the infrared proximity sensor detects if there is input while the inductive and capacitive sensors were calibrated to identify if it is acceptable or not. Weight and cash computation takes part after the object is accepted. The Servo motor works as a gateway in the input verification whether it is a plastic bottle and if it is empty or not. After verification, a plastic bottle is directed to the bin. A message is prompted on the touchscreen monitor if the bin reaches the maximum volume. Lastly, coin dispensing is the main output of the machine being executed by the coin hopper.

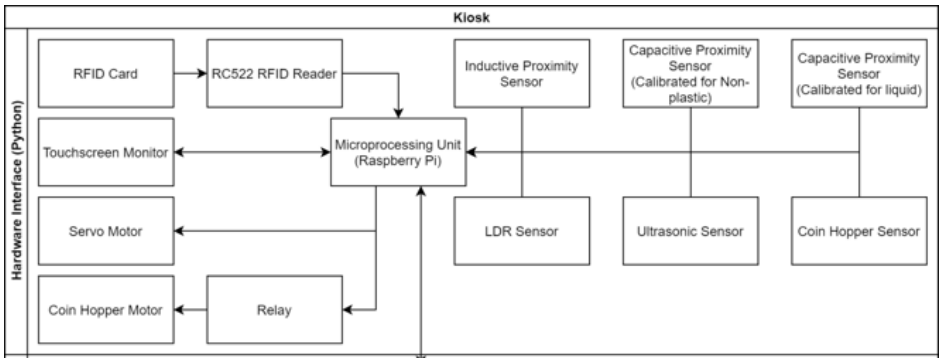

Figure 1. *Block Diagram of the Reversed Vending Machine*

Phase III. Project Implementation

In this phase, a prototype of the machine was built as shown in Figure 2. The prototype was presented during the Engineering Expo to gather feedback from other students, faculty, and staff. All feedback gathered was noted. After prototyping, the actual implementation of the design followed in which the machine was developed on a full scale. During the implementation, all the hardware and software requirements earlier identified were purchased. Each unit was developed and tested for its functionality and then integrated once functional. The entire machine was tested for any faults and failures. Test cases were prepared to determine whether the machine satisfies the requirements or works correctly. The machine was then improved based on the result of the functional testing.

Figure 2. *Prototype of the Machine*

Phase IV. Project Operation

Final testing was done during project operation where the machine was deployed at Barangay Anao for actual use of the target respondents. The functions of the machine were communicated to the target respondents in order for them to understand the use of the machine. Feedback was gathered and a redesign was carried out.

The survey took place after the use of the machine. Questionnaires were distributed to the respondents to evaluate their acceptance of the use of the machine.

Ethical Considerations

In the conduct of the study, the respondents were not subjected to harm in any way. Their participation during the evaluation of the developed RVM was voluntary on the basis of informed consent. All of their personal details were kept anonymous.

Results and Discussion

Project Design

The process flowchart of the machine is presented in Figure 3. The project operation starts from inserting the RFID card and if the card is already registered, the user can start performing transactions. Otherwise, the user has to register his/her RFID card.

The machine provides the user with two options, to withdraw or deposit. In deposit, the capacitive and inductive sensor is equipped to detect if the deposit is acceptable or not. If the deposit is unacceptable, the machine displays a message on the monitor to inform the user about it. Otherwise, the plastic bottle gets displaced into the weighing bin, and adds the total amount to the account of the user.

If the user opts to withdraw, the machine prompts the user to enter the amount and the PIN code. The machine then checks if the amount entered is correct. Once correct, the machine dispenses the equivalent amount of money. Otherwise, the user has to enter again the same required inputs. As soon as the money is completely dispensed by the coin hopper of the machine, the gate of the coin hopper closes.

The schematic diagram of the machine is presented in Figure 4 which served as the basis for the connection of components of the machine. The machine used a Raspberry Pi 3 B processor which served as the board to control the electronic components for physical computing. The machine has one main power supply to support the operation of the machine and function efficiently.

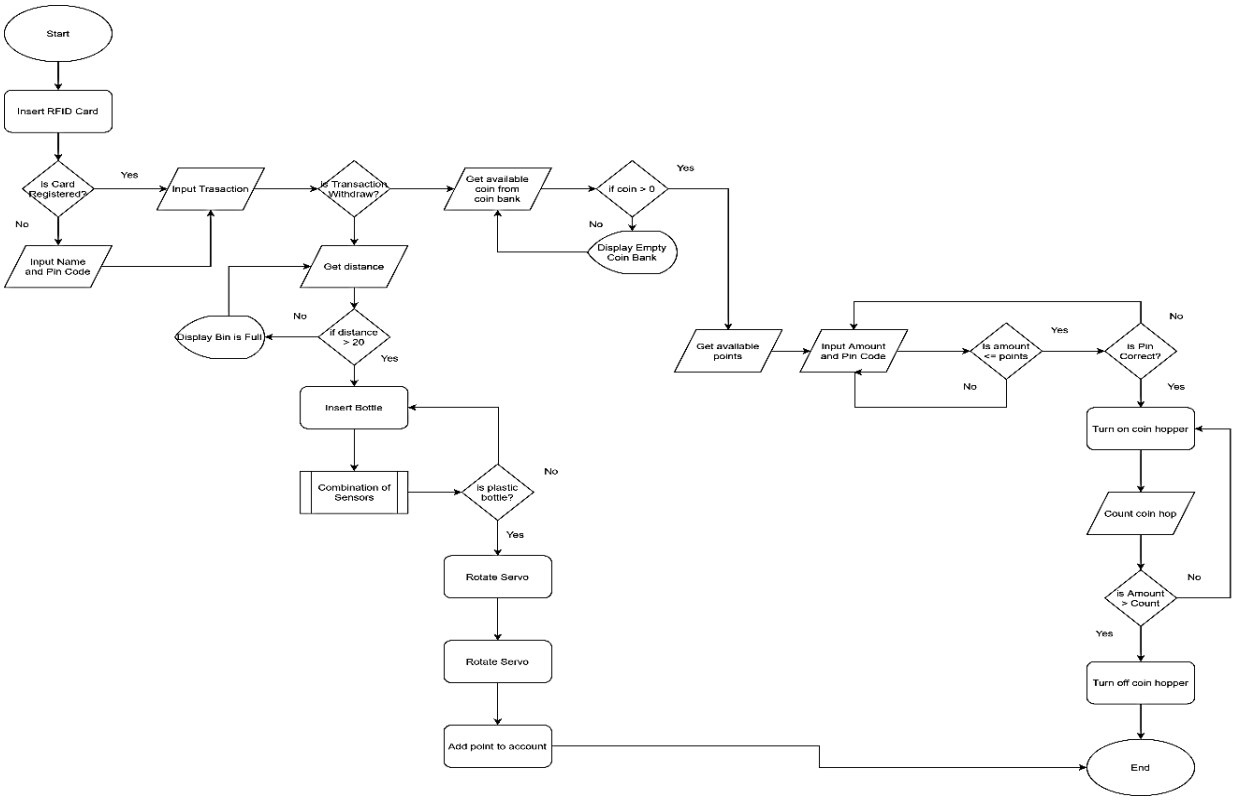

Figure 3. *Process Flowchart*

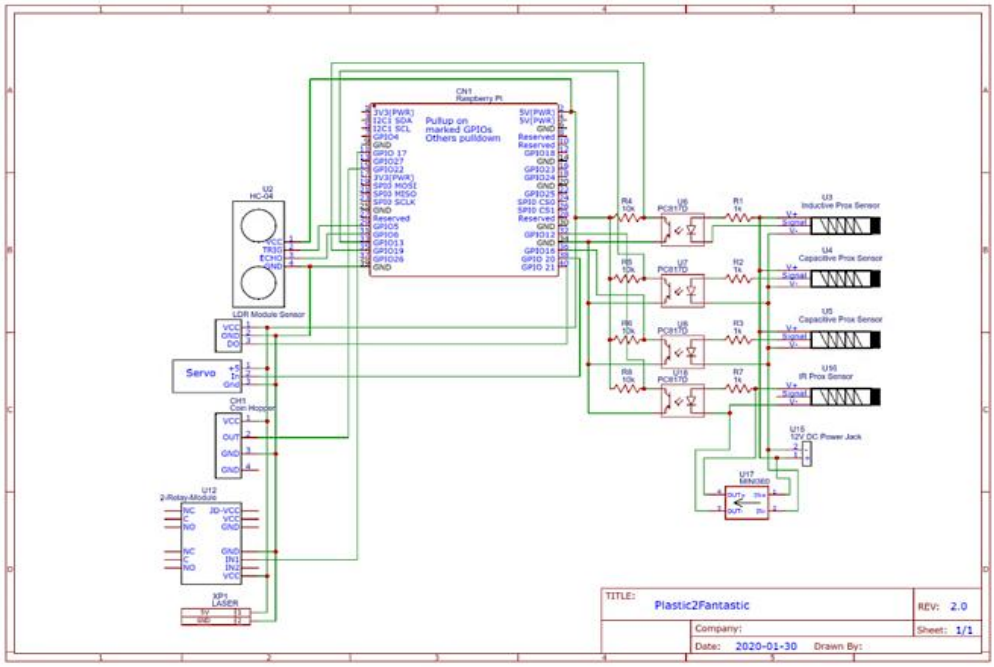

Figure 4. *Schematic Circuit Diagram of the Machine*

The RVM's design perspective is presented in Figure 5. The machine's scale was 150 high and 75 cm wide and designed using the Sketch Up application.

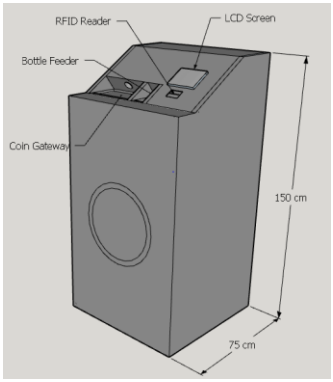

Figure 5. *RVM's Design Perspective*

Project Development

This section presents the result of project development which focused on both the hardware and software components of the machine.

Hardware Development

The final hardware design of the machine, referred to as the "Plastic2Fantastic: Reversed Vending Machine for Plastic Bottles" is presented in Figure 6. The comprehensive design incorporates various components and features essential for its operation. The development cost for constructing the machine amounted to Php 26, 087.00.

Figure 6. *Final Hardware Design of the Machine*

The frame of the machine was built based on the design perspective that was prepared. Its frame as shown in Figure 7 was composed of aluminum. The researchers used aluminum considering the weight of the machine and suggestions from panel members.

Figure 7. *RVM's Frame*

The machine's bottle feeder is presented in Figure 8. It uses the capacitive proximity sensor, inductive proximity sensor, and IR sensor that were placed and used for input detection. The machine used an MGS995 servo motor which was used for the opening of the gate when the input object was accepted.

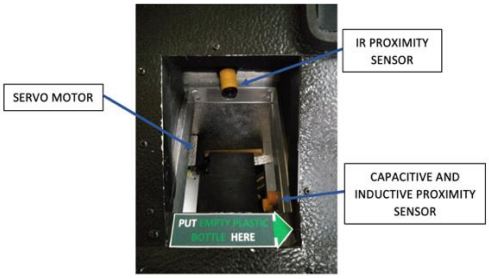

Figure 8. *Bottle Feeder*

The machine also uses an RFID reader and touchscreen LCD for the user interface as shown in Figure 9.

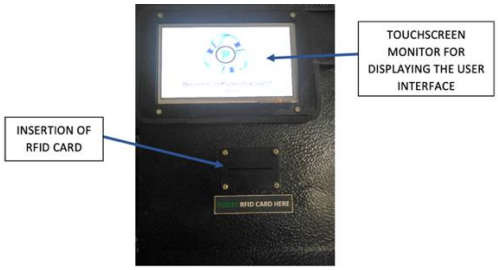

Figure 9. *Registration and Deposit Section*

Coin dispensing is the main output of the machine being executed by the coin hopper. Figure 10 shows the gateway of the coin hopper where coins are being dispensed. Only one peso coin is used by the machine. This is similar to the RVM developed by Patil et al. (2021), which also focused on the concept of cash-from-trash. However, the Plastic2Fantastic RVM distinguishes itself by incorporating RFID technology, making it unique in its approach.

Figure 10. *Withdrawal Section*

Software Development

The Use Case Diagram is presented in Figure 11 which shows the user's interaction with the system. The user interacts with the system by registering an account, logging in and logging out, depositing bottles, and withdrawing cash.

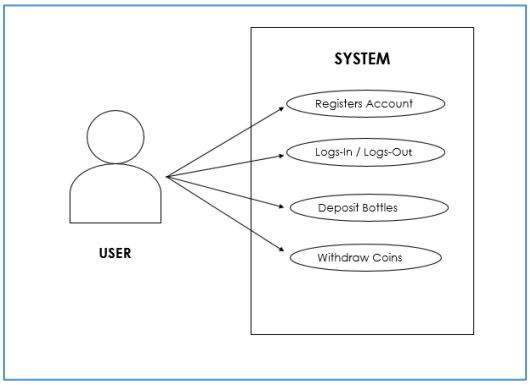

Figure 11. *Use Case Diagram*

User Interface

The home page of the system, as shown in Figure 12, displays a welcome message once the machine is turned on.

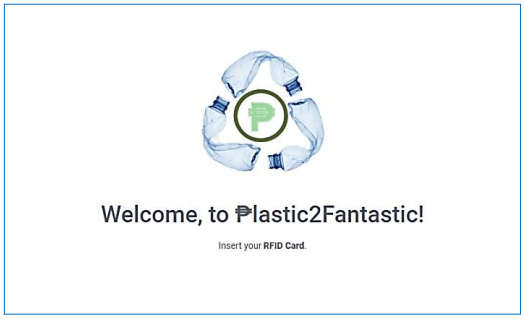

Figure 12. *Home Page of the System*

After tapping the RFID card, the Registration Page and User's Account Page will be displayed, as shown in Figure 13. The system requires the user to fill up the registration form by entering his/her name and PIN code if the RFID Card is not yet registered; otherwise, it goes directly to the User's Account Page, which displays the User's Name, Balance, and also the deposit and withdraw buttons.

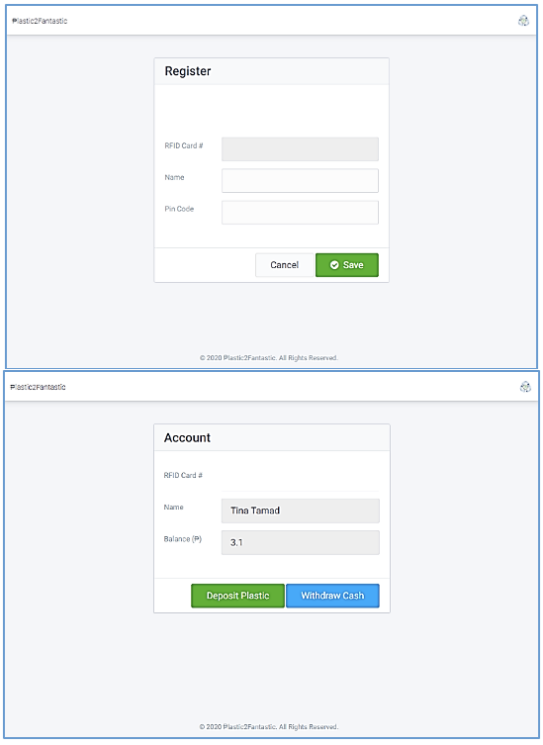

Figure 13. *Registration Page and User's Account Page*

The Deposit Page, as shown in Figure 14, displays the response of the system if the plastic bottle detection was successful or not. It also displays the weight and cash computation of the deposit. The page also has an exit and done button.

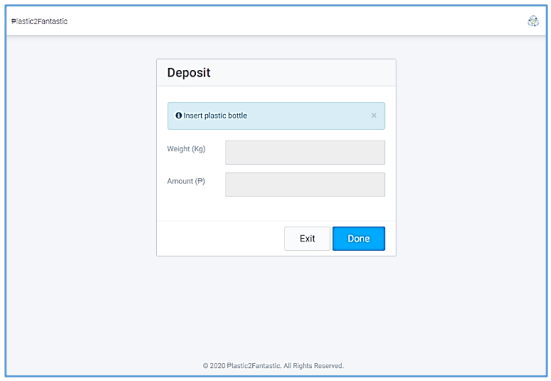

Figure 14. *Deposit Page*

The Withdraw Page, as shown in Figure 15, displays the current balance of the user's account. The page also has a textbox where the user can enter an amount he/she wants to withdraw, and requires the user's PIN code as a verification process.

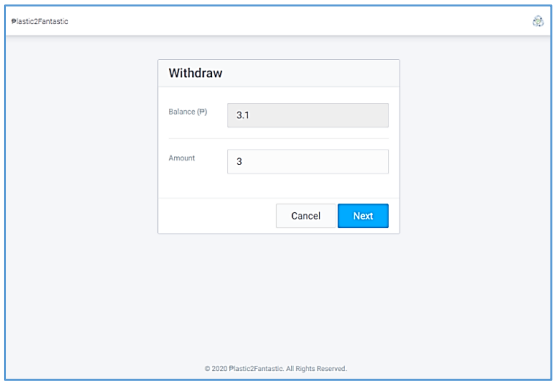

Figure 15. *Withdraw Page*

Project Evaluation

Final testing was done during project operation where the machine was deployed at Barangay Anao for actual use of the target respondents. All respondents expressed strong appreciation for the machine and confirmed that all of its features were functioning properly. The only suggestion provided was to ensure proper labeling of the machine's parts for enhanced usability.

The purpose of this survey was to validate user acceptance in terms of the machine's usefulness and ease of use. The result of the survey on the perceived usefulness of the RVM is presented in Table 2. It could be gleaned from Table 2 that the respondents strongly agreed with the usefulness of the machine based on a calculated overall weight mean of 4.73.

The result of the survey on perceived ease of use is presented in Table 3. It could be gleaned from the table that the respondents strongly agreed with the usefulness of the machine based on a calculated overall weight mean of 4.47.

Table 2. Perceived Usefulness Result

CRITERIA	WEIGHTED MEAN	DESCRIPTION
The machine...		
1. is useful to Local Government Units in proper plastic waste disposal.	4.57	Strongly Agree
2. helps maintain the cleanliness of the area where it is deployed.	4.70	Strongly Agree
3. helps motivate the users to take an interest in terms of recycling.	4.83	Strongly Agree
4. captivates and teaches users how to dispose of plastic waste properly.	4.73	Strongly Agree
5. helps in reducing greenhouse gas emissions and pollution.	4.63	Strongly Agree
6. encourages users to collect and save plastic bottles instead of throwing them.	4.80	Strongly Agree
7. makes recycling collection cleaner and streamlined.	4.70	Strongly Agree
8. contributes to the prevention of plastic pollution.	4.83	Strongly Agree
9. helps in Clean Loop Recycling where plastic bottles can be used again and again to make new containers	4.70	Strongly Agree
10. helps in keeping plastic wastes out of groundwater, oceans, and streets.	4.77	Strongly Agree
Overall Weighted Mean	**4.73**	**Strongly Agree**

Table 3. Perceived Ease of Use Result

CRITERIA	WEIGHTED MEAN	DESCRIPTION
The machine...		
11. is automated with no assistance required.	4.17	Agree
12. is convenient to manage by anyone.	4.33	Strongly Agree
13. provides instructions that are easy to understand.	4.60	Strongly Agree
14. easily recovers from errors encountered while using it.	4.27	Strongly Agree
15. is convenient to use for recycling.	4.63	Strongly Agree
16. is easy for operators to handle, clean, and maintain.	4.23	Strongly Agree
17. is fast and clean, so recycling is more enjoyable.	4.77	Strongly Agree

18. registers account fast and easily.	4.50	Strongly Agree
19. gives updates on savings fast, easily, and accurately.	4.63	Strongly Agree
20. provides transactions like deposits and withdrawals that are not complicated to follow.	4.53	Strongly Agree
Overall Weighted Mean	**4.47**	**Strongly Agree**

Conclusion and Future Works

Based on the findings and results of the study, the researchers concluded that the Plastic2Fantastic: Reverse Vending Machine for Plastic Bottles has successfully satisfied its functional requirements of detecting whether the input material is an empty plastic bottle or not, weighing the plastic bottle deposits, and dispense the correct equivalent amount. It is further concluded that the developed RVM was perceived to be easy to use as well as useful in plastic waste management. This innovation addresses the pressing issue of plastic pollution by promoting recycling and responsible waste disposal, contributing to more sustainable environmental practices.

Based on the results of the study, the following are recommended for future researchers who will undertake similar design projects. Aside from plastic bottles, other materials may be considered as deposits such as cans and bottled glass. The storage bin may be enlarged to accommodate more wastes. Aside from one peso coin, other coins and bills may be considered for the incentive. Moreover, a solar panel as an alternative source of the power supply may also be integrated in case of unexpected electric breakdown. Likewise, for every deposit and withdrawal transaction, a receipt may be considered as another output of the machine. Lastly, other user acceptance evaluation framework may be employed.

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