Design And Fabrication of Reverse Vending Machine "VENDOBIN" With Plastic Shredder for Sustainable Waste Management: Promoting Recycling and Waste Reduction.

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Abstract — The project presents the development of VENDOBIN, a reverse vending machine (RVM)
equipped with a shredding mechanism for the recycling of polyethylene terephthalate (PETE) and high-density polyethylene (HDPE) bottles. This system employs infrared sensors, a load cell, an LCD display, and an Arduino MEGA microcontroller to detect, weigh, and shred plastic bottles, aiming to address the critical issue of plastic waste in Ilocos Norte.

The research objectives included the design and fabrication of the RVM with an integrated shredder, evaluation of its functionality, and optimization of recycling efficiency. The methodology combined quantitative and qualitative approaches. Quantitative experiments focused on testing the machine's shredding capabilities, load capacity, and operational efficiency. Qualitative surveys assessed the attitudes of students towards single-use plastics, their recycling behaviors, and environmental awareness. The development process involved Arduino code creation, precise hardware assembly, and rigorous pretesting and revisions to ensure seamless operation.

Results demonstrated VENDOBIN's effective performance in detecting and processing plastic bottles, optimizing storage, and efficiently shredding PETE and HDPE materials. The shredder's performance metrics varied with different plastic types and sizes, indicating the necessity for optimal settings to enhance efficiency. Survey findings showed a positive trend towards

sustainable practices, with increased environmental awareness and preference for reusable alternatives among students.
The study recommends enhancing the shredder's performance by adding more blades and a finer mesh, integrating the university's RFID database for incentivized recycling, and exploring the use of shredded plastics in creating Eco-bricks and 3D printing filament. VENDOBIN provides a innovative solution for plastic waste management, promoting sustainability and setting a benchmark for future recycling technologies.

Keywords — Reverse vending machine, plastic shredding, recycle, shredding capabilities, PETE bottles, HDPE bottles, plastic waste management, recycling, environmental sustainability, infrared sensors, load cell, Arduino MEGA, recycling efficiency

I. Introduction

T With rising economic growth, human consumption increases, leading to the rapid use and production of single-use plastics. The plastic industry in the Philippines contributes to the national economy and provides low-cost consumer goods to poor and middle-income families. However, this high dependence on singleuse plastics exacerbates the already alarming levels of marine plastic pollution. Developing countries like ours struggle with sustainable plastic production, consumption, and proper solid waste management.

The increasing population, rapid urbanization, and changing consumption patterns have led to a significant rise in waste generation. According to the National Solid Waste Management Commission, the Philippines generates around 40,000 tons of waste per day, with only a small portion being recycled or properly disposed of (Department of Environment and Natural Resources, 2019). This situation poses serious environmental and health risks, including pollution of land, water bodies, and air, as well as the proliferation of diseases.

The Philippines faces a major waste management problem, with increasing amounts of garbage generated every year. According to the National Solid Waste Management Commission in 2018, the Philippines produces over 40,000 tons of waste daily, with only 73% collected and just 9% recycled. This issue is also evident in Ilocos Norte, a province in the northern region of the Philippines, which generates significant waste due to its growing population and tourism industry.

In Ilocos Norte, waste management is critical for maintaining its pristine environment and safeguarding its natural allure (Garcia & Santos, 2020). Renowned for its abundant cultural heritage and tourist attractions, the province acknowledges the pivotal role of sustainable waste management strategies in preserving its ecological resources and sustaining its allure as a sought-after tourist destination (Lopez et al., 2019).

The waste management concern in our country is addressed through Republic Act 9003, also known as the "Ecological Solid Waste Management Act of 2000." Despite government efforts to increase public awareness about solid waste management, sustaining these efforts remains challenging and requires a fundamental shift in individual mindsets and behaviors. Given the urgent need to address growing plastic waste and the scarcity and high cost of landfills, new waste management approaches are necessary.

Reverse vending machines (RVMs) are automated recycling systems that collect, sort, and process empty beverage containers for reuse. They incentivize recycling by offering financial or other rewards for returned containers, reducing waste and promoting sustainability. Reverse Vending Machines have been implemented in several countries worldwide, and their effectiveness in reducing waste has been widely studied. However, little research has been conducted on their adoption and impact in developing countries.

This study aims to design and fabricate Reverse Vending Machines (RVMs) tailored to the specific waste management needs of a university in Ilocos Norte. By incorporating a shredder into the design, the machines will provide a more compact and mobile solution, effectively managing waste in one location. This initiative hopes to promote recycling behaviors, reduce waste generation, and enhance overall waste management practices on campus. Additionally, the study aims to contribute to existing knowledge on sustainable waste management systems, recycling behavior, and the role of technology and engineering in promoting environmental stewardship. Ultimately, the project aspires to foster a culture of sustainability and responsibility within the university community.

Objectives of the Study

Generally, this study aimed to fabricate a reverse vending machine installed with an automatic plastic shredder. Specifically, the objectives are:

1. Assess the Functionality of the reverse vending machine thru:

    a. evaluating its proper functioning; and

    b. verifying the accuracy of waste item material recognition and acceptance.

2. Analyze the effectiveness of the plastic shredder.

3. Measure the shredding mechanism of the machine in terms of:

    a. plastic waste material input thickness;

    b. shredded size;

    c. capacity; and

    d. speed.

Literature Review

A reverse vending machine (RVM) is revolutionizing the recycling industry by providing efficient solutions for waste beverage containers. Reports show that about 425 beverage containers are generated per capita per year in the United States. This surge in waste demands a high rate and frequency of recycling, and RVMs offer an efficient service to address this problem. RVMs automate the collection, segregation, and recycling of discarded beverage containers, providing significant environmental benefits by reducing litter, preventing plastic waste from reaching oceans and other water bodies, and minimizing landfill waste.Recycling also facilitates the reuse of waste containers, decreasing the need for new raw materials and positively impacting the environment.

With nations increasingly adopting policies concerning recycling and sustainability, RVMs have become standard in areas with stringent recycling regulations. To date, there are over one hundred thousand RVMs globally, located in countries including the United Kingdom, Russia, Norway, Sweden, Canada, and the United States. An RVM allows people to return empty beverage containers, such as bottles and cans, for recycling. The machine often provides a deposit or refund, making it a "reverse" vending machine: instead of the user putting in money and receiving a product, the user puts in a product and receives a monetary value. RVMs are particularly common in regions with container deposit laws and mandatory recycling legislation.

Reverse vending machines function through a series of actions. Initially, the recycler inserts empty beverages into the receiving hole. The bottle or can is then rotated to allow the Universal Product Code (UPC) scanner to read the UPC, which identifies the manufacturing facility. Once examined and identified, the bottle is added to the database to track the number of bottles the recycler is recycling. The containers are then broken down into smaller sizes to maximize storage space. Recycling customers can choose their rewards. When the storage capacity is filled, the beverage containers are sorted and delivered to recycling companies. This process enhances the efficiency of sorting waste and improves the recycling process.

RVMs provide numerous advantages, including aiding environmental conditions by recycling materials and decreasing the demand for raw materials in producing new beverage containers. They are conveniently placed in public areas such as supermarkets, gas stations, parks, and schools, making them easily accessible for people.

Polyethylene terephthalate (PET) is a common thermoplastic polymer resin used in beverage bottles and other packaging materials. PET bottles are widely used by manufacturers for carbonated beverages, water bottles, food jars, edible oils, detergents, cosmetics, and pharmaceutical products. Because plastic is non-biodegradable, it is essential to recycle PET to prevent environmental pollution. The recycling process starts with collecting plastic bottles, sorting them into different categories, and then crushing or melting them to form pellets or new products. In other countries, such as Norway and Japan, RVMs have been successfully implemented. For example, TOMRA Japan has placed around 1,200 RVMs, collecting 300 million PET bottles annually (Chung, 2019). The RVMs are placed in accessible areas, such as convenience stores, encouraging users to recycle and saving time.

In Malaysia, RVMs are still in the process of being introduced and installed across the country. Previous research on RVMs and shredding machines has explored various designs of cutters used to crush plastic bottles, different types of controllers, and mechanisms for money dispensing similar to vending machines. Discrete sensors are commonly used to detect and recognize plastic bottles, preventing different recyclable materials from mixing. A study by Deena Mariya in 2020 utilized an image processing system to identify and credit points for plastic bottles. Sinaga's study proposed a barcode scan system for RVMs to sort plastic bottles and cans by comparing barcodes with a developed database. Pulley mechanisms and jaw couplings are used in shredding machines to handle plastic bottles effectively.

Plastic shredding machines cut plastic materials into smaller pieces, reducing the volume of plastic waste and making it easier to transport and process for recycling. These machines come in various sizes and designs, from small hand-held units to large industrial machines. Some are designed for specific types of plastic, such as PET bottles, while others can handle a wide range of plastic materials. The benefits of using plastic shredding machines include saving space in landfills and making plastic waste easier to handle and recycle.

Designing a plastic recycling machine that combines conveying and heating to shred and melt plastic has been attempted, although optimization is needed for efficient output. Shredding machines, inspired by traditional methods like scissors and rabbit scratching techniques, are used to reduce plastic waste size, making it easier to handle and recycle. The machines typically consist of four main components: the feed part, the shred part, the power unit, and the machine frame.

According to the United Nations Environment Programme (UNEP) in 2018, only 9% of the nine billion tons of plastic ever produced has been recycled, with most ending up in landfills, dumps, or the environment. In developing countries, including Malaysia, inadequate waste management infrastructure hampers recycling efforts. Custom-made shredder machines designed for small to medium-scale recycling have been documented, highlighting various designs and techniques for effective plastic waste management.

II. Methodology

Research Design

The research team employed a comprehensive approach, integrating quantitative and qualitative methods to investigate the functionality of the Reverse Vending Machine 'VendoBin' (RVM) with a built-in plastic shredder.

Quantitative Component:

Utilized experimental research methods to design and construct the innovative RVM. Focused on assessing loading capacity and shredding efficiency to gain insights into its performance.

Qualitative Component:

Gathered data through surveys and questionnaires. Explored attitudes, behaviors, and motivations related to single-use plastic consumption among students within the College of Engineering, Architecture, and Technology (CEAT). Aimed to uncover factors influencing plastic usage, raise awareness of environmental impact, explore disposal habits, and evaluate student receptiveness to sustainable waste management initiatives.

Design of the VendoBin

The reverse vending machine 'VendoBin', equipped with a built-in plastic shredder, revolutionizes recycling practices with its innovative design. Inspired by traditional vending machine aesthetics, 'VendoBin' seamlessly integrates a powerful shredding mechanism. This feature allows users to deposit plastic bottles and containers directly into the machine for efficient onsite shredding. By combining recycling and shredding capabilities in a single unit, 'VendoBin' promotes convenience and sustainability, encouraging responsible plastic waste recycling while minimizing environmental impact.

Design of the Shredder

The plastic shredder features a single shaft arrangement with six dynamically rotating blades and three stationary blades, meticulously designed for optimal material processing. It operates efficiently with a 1.5 horsepower electric motor, connected via a dual A-39 belt system for seamless power transmission. Each blade is crafted from durable 2mm thick metal plates, chosen for their resilience under shredding conditions. At the bottom, the shredder is equipped with a mesh comprising holes with 2-3mm diameter. This design facilitates efficient discharge of shredded materials while preventing debris buildup, ensuring continuous operation.

Fabrication of the VendoBin

Fabricating the VendoBin reverse vending machine with an integrated plastic shredder involves several critical steps to ensure functionality and durability. The process begins with meticulous planning, considering the machine's dimensions and specifications. The frame, measuring 1.5 meters in width and 2 meters in height, is primarily constructed using angle bars to provide robust support for both the vending and shredding components. For user visibility and durability, the enclosure combines plywood and acrylic glass, selected for their structural integrity and aesthetic appeal in challenging recycling environments.

Once the design and materials are finalized, fabrication commences with precision component manufacturing. Each part, including the vending mechanism, shredder, and control panel, is crafted with attention to detail to ensure seamless integration and operational efficiency. Assembly requires careful coordination, with researchers aligning and connecting components precisely according to design specifications. Electrical wiring and components are installed to power the machine and control its functions, ensuring optimal performance. Following assembly, rigorous testing and calibration validate the VendoBin's functionality and performance. The shredder's cutting blades are finely tuned for maximum efficiency, while sensors and control systems undergo thorough testing for accuracy and reliability. Any identified issues are promptly addressed to meet stringent quality standards. Upon successful testing, finishing touches such as branding and signage are applied to enhance the machine's aesthetics and user experience.

Electronic Components in the VendoBin Reverse Vending Machine

The VendoBin reverse vending machine integrates various electronic components to ensure smooth and efficient operation.

RFID (Radio Frequency Identification) Technology: Utilizes radio waves for object identification and tracking, crucial for effective inventory management and access control.

Main Servo Motor (MG996R): Provides precise control over rotational or linear movements, essential for accurate item handling within the machine.

Infrared Sensors: Serve dual roles as item detectors and counters, enabling precise tracking of item movement for efficient processing.

Load Cell: Converts force into an electrical signal, enabling precise weight measurement. Coupled with a servo motor (MG996R) for movement control, it enhances weight sensing accuracy.

12 Volts DC Linear Actuator: Facilitates controlled linear motion, essential for specific machine functionalities.

Automotive Wire and Jump Wires: Establish secure electrical connections between components.

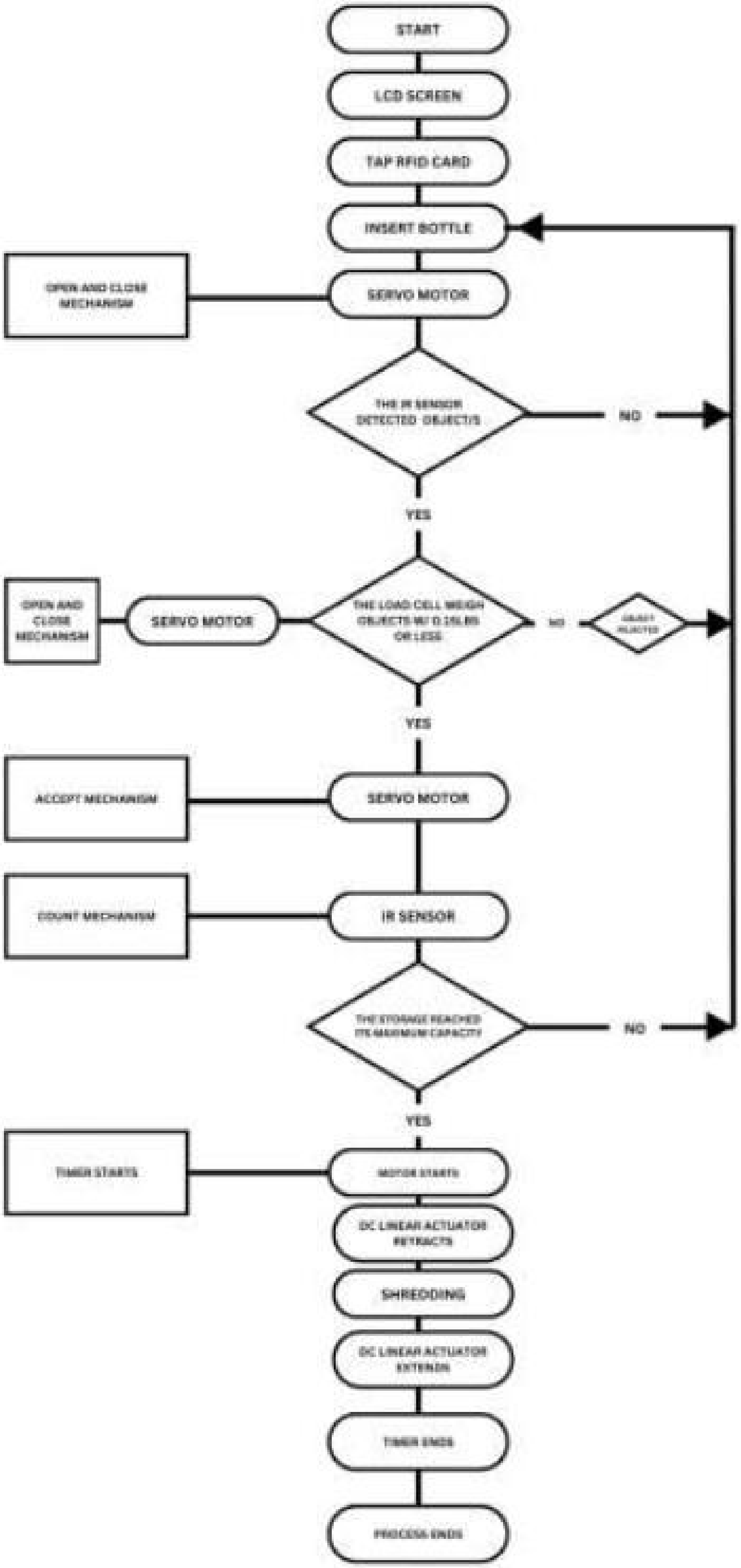
8-Module Relay: Manages electrical current flow to different circuits.

LED Strips: Provide illumination for enhanced visibility and aesthetics, supported by circuit breakers for safety against electrical faults. Contactors: Oversee high-power circuits, ensuring smooth operation. Power Supplies: 5 Volts and 12 Volts power supplies ensure stable and consistent electrical delivery.

Arduino Mega Microcontroller Board: With extensive I/O capabilities and processing power, enables complex functionalities within the machine.

Push Buttons: Allow for easy control over power states and specific functions within the VendoBin reverse vending machine.

Circuit Flowchart



Data Collection Process

The researchers outlined a series of steps to gather reliable information on designing and fabricating the reverse vending machine "VendoBin" equipped with a plastic shredder, aimed at promoting recycling and waste reduction.

Criteria Establishment: Specific metrics were determined to evaluate the machine's functionality. These included the accuracy of bottle recognition, the efficiency of the recycling process, and the reliability of issuing refunds. Additional metrics were specified to assess the plastic shredding mechanism, such as the time required to shred different plastic materials and its capacity in terms of weight and volume.

Testing Setup: Controlled experiments were set up, wherein plastic items of verified thickness and sizes were fed into the machine.

Observation: The reverse vending machine was observed in action, with monitoring focused on how it managed several types of bottles, whether it dispensed refunds correctly, and if it experienced any technical issues.

Time Measurement: Timing devices were used to record the time taken for the machine to shred each plastic item. This process was repeated with multiple samples of each plastic type.

Measurement: The maximum capacity of the shredding mechanism was determined by gradually increasing the input until it could no longer process efficiently the plastic.

Technical Testing: Technical tests were conducted to measure the accuracy in a structured manner of the machine's function, such as weighing the returned bottles.

Data Recording: All observations, feedback, test results, and measurements were recorded in a structured manner. This included noting the type of plastic, its thickness, and size upon input, as well as the shredding time and the point at which the machine reached its capacity limit.

Analysis: The collected data was analyzed to identify trends, patterns, and any significant differences in shredding time and capacity based on the characteristics of the plastic.

Participants

The research methodology for this study employed a dual approach. Researchers conducted tests on the Reverse Vending Machine (RVM) prototype 'VendoBin' themselves for data collection. Simultaneously, a sample was selected by randomly choosing ten students from Northwestern University's College of Engineering, Architecture, and Technology. These students were invited to voluntarily participate in the study and provide responses to a structured questionnaire. Ethical considerations and adherence to data protection protocols were ensured through the acquisition of informed consent from the selected students.

This comprehensive strategy combined self-testing by researchers with external participant involvement, aiming to provide a thorough understanding of the RVM prototype's performance and user experiences.

Research Instrument

The research instrument consisted of two distinct parts, each serving specific purposes in our investigation.

Part I: Played a pivotal role in enabling data collection, analysis, design, and development—all essential elements contributing to a comprehensive thesis on the design and fabrication of the VendoBin sustainable waste management. This segment unearthed valuable insights into user preferences, expectations, and concerns related to recycling and waste reduction. To achieve this, the research team conducted an extensive review of pertinent literature, including academic papers, articles, and patents closely related to reverse vending machines, plastic shredders, waste management, and recycling technologies.

Leveraging Computer-Aided Design (CAD) software, the researchers meticulously crafted and simulated the machine's design to ensure seamless operation and integration of both the vending and shredding components. Rigorous analysis followed, where each prototype underwent comprehensive performance evaluations. Detailed assessments encompassed operational efficiency, durability, user-friendliness, and safety, forming the bedrock for our research and development endeavors.

Part II: Focused on gathering feedback from CEAT students through comprehensive surveys and questionnaires, specifically targeting their attitudes, behaviors, and motivations concerning single-use plastic consumption. Researchers diligently sought informed consent from participants and guaranteed the confidentiality of their responses throughout the data collection process. To encourage candid and honest input, anonymous questionnaires were employed, creating an environment where students felt comfortable sharing their perspectives. Recognizing the limitations of this approach, researchers took meticulous steps to ensure data accuracy, reliability, and completeness, minimizing the potential for misinterpretation or bias in the survey responses. The responses from CEAT students were instrumental in shaping and refining the design and functionality of the VendoBin.

This multi-faceted research instrument approach enabled the research team to glean comprehensive insights into both the technical aspects of the VendoBin and the user perspectives of CEAT students. It ultimately aimed to design a sustainable solution for waste management, emphasizing recycling and waste reduction.

III. Results and Discussion

This chapter presents the results of the data gathered during the actual testing of the developed Reverse Vending Machine 'VendoBin' with a plastic shredder.

SURVEY

The survey results reveal a comprehensive understanding of participants' consumption habits, environmental awareness, and preferences regarding single-use plastics. Here are the key findings:

Usage Patterns: Most respondents rely on 1-3 single-use plastic items daily, indicating a prevalent dependence on such products in their daily routines.

Preference for Reusables: A significant number of participants actively choose reusable alternatives, signaling a positive shift towards sustainable choices.

Environmental Awareness: The majority demonstrate notable awareness of the environmental impact of single-use plastics, with many considering themselves 'very aware' or 'somewhat aware.'

Recycling Efforts: Many respondents regularly make efforts to recycle plastic items, demonstrating a proactive approach to waste management.

School Initiatives: Participants show widespread awareness of plastic reduction initiatives within educational settings, indicating a positive response to sustainability efforts.

Peer Influence: Social norms significantly influence individual choices regarding single-use plastics, highlighting the impact of peer influence on behavior.

Brand Preference: Coca-Cola emerges as the preferred brand for single-use plastic items, indicating the influence of brand recognition and market presence.

Recycling Practices: The divide between recycling and trash disposal underscores the need for improved recycling infrastructure and awareness campaigns.

Motivators for Reduction: Environmental awareness is the primary motivator for reducing single-use plastic consumption, emphasizing the importance of education and awareness initiatives.

Demand for Eco-Friendly Options: A majority of respondents express a preference for vending machines offering eco-friendly packaging options, reflecting growing demand for sustainable consumer choices.

The survey highlights both opportunities and challenges in promoting sustainable practices and reducing single-use plastic consumption. Continued efforts in education, awareness-raising, and availability of eco-friendly alternatives are crucial in addressing environmental concerns and fostering a culture of sustainability among consumers.

Table 01. Plastic bottles as input.

Plastic Sample	Number of Trials	Number of Successful Trials	Percentage Accuracy
Mixed Bottles	10	10	100%
Mismo	10	10	100%
Nature's Spring, Wilkins	10	10	100%
Crystal Dew	10	10	100%
Sting	10	10	100%
Nature's Spring, Wilkins	10	9	90%
Coke Sakto	10	10	100%
Gatorade	10	10	100%

The data in Table 01 provides a detailed evaluation of the performance accuracy of a shredding process or machine applied to various plastic bottle samples. Each sample underwent 10 individual trials. The results indicate that for the majority of the plastic bottle samples—Mixed Bottles, Mismo, Nature's Spring, Wilkins (first set), Crystal Dew, Sting, Coke Sakto, and Gatorade—the machine achieved a perfect accuracy rate of 100%, with all 10 trials meeting the criteria successfully. However, a second set of trials for the Nature's Spring and Wilkins sample revealed a slightly lower accuracy rate of 90%, with 9 out of 10 trials being successful. This minor deviation suggests potential variability in the process or specific material characteristics affecting the outcome. Overall, the shredding process or machine demonstrates a high level of reliability and precision, maintaining 100% accuracy across 7 out of 8 different plastic bottle samples, with only one instance showing a slight reduction in accuracy.

Table 02. Negative inputs.

Sample	Number of Trials	Number of Successful Trials	Percentage Accuracy
Aluminum Can	10	0	100%
Juice Containers	10	0	100%

Table 02 presents the results of trials conducted on non-plastic samples to evaluate the accuracy of a process or machine in rejecting unsuitable materials. The samples, aluminum cans and juice containers, underwent 10 trials each. The results indicate that for both aluminum cans and juice containers, none of the trials were successful, resulting in a 100% accuracy rate for rejection in each case. This data demonstrates the machine's effectiveness in accurately identifying and rejecting non-plastic materials, ensuring that only appropriate plastic samples are processed.

Table 03. Overall performance of the VENDOBIN.

FUNCTION	YES	NO
Could it detect a RFID card?	✓	
Is the infrared sensor capable of detecting plastic bottle materials?	✓	
Can the load cell measure the weight of objects?	✓	
Can the servo motor respond if the bottle is accepted?	✓	
Can the infrared sensor detect when the storage pit reached its maximum capacity?	✓	
Did the shredder turned on automatically after the capacity of the storage was full?	✓	

Table 03 presents the overall performance of the VendoBin, confirming the system's capability to successfully detect an RFID card, ensuring seamless identification processes. Moreover, the infrared sensor demonstrates proficiency in detecting plastic bottle materials, enhancing its versatility for sorting and identification tasks. Furthermore, the integration of a load cell enables accurate measurement of object weights, thereby enhancing overall precision and functionality. Additionally, the servo motor's responsive action upon bottle acceptance ensures smooth operational flow, a critical aspect in automated systems.

Lastly, the infrared sensor's ability to monitor storage pit capacity and signal when it nears maximum capacity underscores its role in optimizing storage efficiency and preventing overflow situations. Notably, the shredder automatically turns on after the storage pit is full, demonstrating the system's holistic approach to effectively managing waste autonomously. Together, these findings demonstrate the system's effectiveness across a range of functionalities.

Table 04. Testing of the fabricated plastic shredder.

Plastic Sample	Volume of Bottle (mL)	Type of Plastic	Volume of Bottle in (m^3)	Number of Pieces	Total weight of bottles (g)	RPM	Shredding Duration (seconds)	Smallest output (mm)	Biggest output (mm)
Mixed Bottles		PET		20	620	1779	86.93	3	176
Mismo	290	PET	0.00029	20	360	1785	84.4	4	95
Nature's Spring, Wilkins	500	PET	0.0005	16	245	1780	87.74	4	118
Crystal Dew	500	PET	0.0005	15	355	1778	78.03	6	130
Sting	320	PET	0.00032	23	580	1781	62.15	3	109
Crystal Dew	320	PET	0.00032	21	475	1785	80.45	4	102
Nature's Spring, Wilkins	330	PET	0.00033	20	320	1791	90.13	2	180
Coke Sakto	190	PET	0.00019	34	600	1782	80.6	2	106
Gatorade	350	PET	0.00035	20	800	1771	119.12	2	70
Mixed Bottles	1000	PET	0.001	8	225	1776	107.68	3	147

Table 04 presents data gathered from the Testing of the Fabricated Plastic Shredder, offering insights into plastic shredding outcomes exclusively focusing on PET (Polyethylene terephthalate) bottles, a common polymer. Across the PET bottle samples, significant variability is observed in shredding metrics, such as the number of pieces generated and the total weight before and after shredding. For instance, 'Gatorade' bottles yielded the highest weight after shredding at 800 grams, while 'Mixed Bottles' resulted in the lowest weight at 225 grams. This diversity underscores the influence of bottle volume and plastic type on shredding effectiveness. PET bottles consistently demonstrate a tendency to produce more pieces and smaller output sizes compared to HDPE (High-Density Polyethylene) bottles, which are not represented in this dataset. Specifically, 'Sting,' a PET bottle, generated 23 pieces, while 'Crystal Dew,' another PET bottle, produced 15 pieces. Operational parameters such as shredding duration and RPM values vary across samples. For instance, 'Gatorade' bottles had the longest shredding duration at 119.12 seconds, while 'Sting' bottles had the shortest at 62.15 seconds. The data indicates significant variability in shredding outcomes across different PET bottle samples. PET bottles consistently exhibit efficient shredding characteristics, highlighting their suitability for recycling applications. The variability in operational parameters underscores the importance of optimizing shredder settings for each plastic sample to enhance recycling efficiency further. Further research may be warranted to explore optimal shredding conditions for differentPET bottle designs, contributing to the advancement of plastic recycling efforts.

Table 05. Testing of the commercially available plastic shredder.

Plastic Sample	Volume of Bottle (mL)	Type of Plastic	Volume of Bottle in (m^3)	Number of Pieces	Total weight of bottles (g)	RPM	Shredding Duration (seconds)	Smallest output (mm)	Biggest output (mm)
Mixed Bottles		PET		20	620	1635	100.26	3	100
Mismo	290	PET	0.00029	20	360	1636	45.62	5	92
Nature's Spring, Wilkins	500	PET	0.0005	16	245	1639	61.2	4	86
Crystal Dew	500	PET	0.0005	15	355	1639	61.62	5	127
Sting	320	PET	0.00032	23	580	1635	72.34	3	75
Crystal Dew	320	PET	0.00032	21	475	1542	45.67	2	117
Nature's Spring, Wilkins	330	PET	0.00033	20	320	1637	68.72	4	90
Coke Sakto	190	PET	0.00019	34	600	1638	48.5	2	64
Gatorade	350	PET	0.00035	20	800	1633	127.85	3	80
Mixed Bottles	1000	PET	0.001	8	225	1637	68.16	3	86

Table 05 presents the data gathered from testing a commercially available shredder, offering valuable insights into plastic shredding outcomes exclusively focusing on PET (Polyethylene terephthalate) bottles, a common polymer. Notable variations are observed across different PET bottle samples, with significant differences in metrics such as the number of pieces generated and the total weight before and after shredding. For instance, 'Gatorade' bottles yielded the highest weight after shredding at 800 grams, while 'Mixed Bottles' resulted in the lowest weight at 225 grams. PET bottles consistently demonstrate a tendency to produce more pieces and smaller output sizes compared to other plastic types. Operational parameters such as shredding duration and RPM values also exhibit variability among samples. For instance, 'Gatorade' bottles showed the longest shredding duration at 127.85 seconds, while 'Mismo' bottles had the shortest at 45.62 seconds. The data indicates significant variability in shredding outcomes across different PET bottle samples. PET bottles consistently exhibit efficient shredding characteristics, highlighting their suitability for recycling applications. The variability in operational parameters underscores the importance of optimizing shredder settings for each PET bottle sample to enhance recycling efficiency further. Further research may be warranted to explore optimal shredding conditions for different PET bottle designs, contributing to the advancement of plastic recycling efforts.

Table 04 vs Table 05: Results from the comparative analysis of the performance of a fabricated plastic shredder and a commercially available plastic shredder.

The data from Tables 04 and 05 present a comparative analysis of the performance of a fabricated plastic shredder and a commercially available plastic shredder, both exclusively tested on PET (Polyethylene terephthalate) bottles.

The fabricated shredder, powered by a 1.5 HP electric motor, exhibited significant variability in shredding performance, with shredding durations ranging from 62.15 seconds to 119.12 seconds, and output sizes varying from 2 mm to 180 mm. In contrast, the commercially available shredder, operating at an effective 3.5 HP, showed more consistent but still variable results, with shredding durations between 45.62 seconds and 127.85 seconds, and output sizes ranging from 2 mm to 127 mm.

Both shredders demonstrated the capability to handle different PET bottle samples, producing similar ranges of output sizes and weights. However, the commercially available shredder generally achieved faster shredding times, likely due to its higher effective horsepower. Despite its lower power, the fabricated shredder performed comparably in terms of output size distribution, suggesting that with optimization of motor power and operational parameters, it could match or even exceed the efficiency of the commercial shredder.

Remarkably, the fabricated shredder has proven to possess the quality of the commercially available shredder while operating at a lower horsepower, indicating significant efficiency. This comparison highlights the potential for optimized, lower-power shredders to achieve high performance in plastic recycling applications.

Table 06. Continuous shredding test results for one sack of plastic bottles.

Plastic Sample	Type of Plastic	Number of Pieces	Total weight of bottles (g)	RPM	Smallest output (mm)	Biggest output (mm)
Mixed Bottles	PETE and HDPE	137	4328	1779	3	103

The data represents the results of continuously shredding one sack of mixed plastic bottles composed of PETE (Polyethylene Terephthalate) and HDPE (High-Density Polyethylene). The sack contained 137 bottles, totaling 4328 grams in weight. The shredding machine operates at a speed of 1779 RPM (rotations per minute), indicating a high blade rotation rate for efficient shredding. The output from this process varies in size, with the smallest shredded pieces measuring 3 millimeters and the largest pieces reaching 103 millimeters. This variability suggests that while the machine effectively shreds the bottles, the resulting plastic pieces have varying sizes, which may necessitate further processing or sorting to ensure uniformity in recycling applications.

The storage box reached its maximum capacity when filled with the shredded plastic from the 137 bottles. The dimensions of the storage box are 30 cm in height, 45 cm in length, and 50 cm in width. Using the formula:

$$V = l \times w \times h$$

$$V = 67,500\ cm^3$$

Converting this to cubic meters, we get:

$$V = 0.0675\ m^3$$

IV. Conclusion

Through comprehensive testing, the VENDOBIN demonstrated exceptional functionality by accurately detecting RFID cards, identifying plastic bottle materials, and efficiently measuring object weights. The machine's responsive servo motor ensured smooth operational flow, while its capacity monitoring feature prevented overflow, optimizing storage efficiency. Importantly, automatic activation of the shredder upon reaching full capacity underscored the system's comprehensive waste management approach.

Additionally, the study scrutinized the effectiveness of the plastic shredder, evaluating its performance concerning input thickness, capacity, and speed. Significant variability was observed in shredding outcomes, with PETE bottles demonstrating efficient shredding characteristics across different operational parameters. Notably, the findings highlighted the importance of optimizing shredder settings for enhanced recycling efficiency.

Overall, the study successfully achieved its objectives, providing valuable insights into the functionality of the VENDOBIN and the effectiveness of plastic shredding technologies. These contributions are significant for advancing plastic recycling practices.

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