Second-Life Bins: Design and Functionality of a Smart PET Bottle Trash Bin as Waste Reduction Initiatives

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Chapter 1

INTRODUCTION

A. Background of the Study

Communities across the Philippines are increasingly feeling the impact of plastic pollution from clogged drainage systems and unsightly litter to the broader threats it poses to marine life and human health. A major contributor to this crisis is the widespread use of single-use plastic, particularly PET (Polyethylene Terephthalate) bottles, which is a type of polymer commonly used to produce plastic bottles. These PET bottles are highly reusable and can undergo various recycling processes such as intensive washing, remelting, and conversion into new PET products (Natural Mineral waters Europe, 2022). These bottles, while recyclable, often end up in streets, rivers, and oceans due to poor waste management systems and lack of accessible recycling options.

In response to the alarming threat of the increasing amount of plastic waste, including PET materials, that has negatively affected the environment globally, many researchers have tried to come up with different solutions to this problem. Smart bins often incorporate sensors and image processing techniques to differentiate between biodegradable, non-biodegradable, and recyclable plastics, such as PET bottles (Kulkarni et al., 2024). Many smart bins are equipped with IoT capabilities to monitor waste levels in real time and communicate this data to waste management authorities. This allows for optimized collection scheduling, preventing overflow and minimizing environmental health risks (Flores et al., 2023). To promote and encourage the population, some smart bins integrate reward mechanisms, sometimes called RVM (Reverse Vending Machines), to encourage responsible disposal of plastic waste, increasing public participation in recycling initiatives (Fteiha et al., 2024). But despite advancements in recycling technologies, only a small fraction (around 9%) of plastic waste, including PET, is effectively recycled globally. The majority is either landfilled, incinerated, or discarded in the natural environment, where it accumulates due to slow degradation rates. PET bottles have become a critical focus due to their high usage and environmental footprint (Thiounn & Smith, 2020). Adding to this, the high cost of deploying smart waste bins limits their widespread adoption, especially in developing countries where budget constraints and technological infrastructure hinder large-scale implementation. Maintenance costs, technology upgrade expenses, and the reluctance to change established waste management procedures further impede scalability (Otegbalor et al., 2024).

This study specifically seeks to design and propose the functionality of a Smart PET Bottle Trash Bin which will tackle concerns regarding waste reduction initiatives. The researchers aim to create a trash bin that doesn't only encourage proper disposal of PET bottles but also integrates smart features like sensor-driven detectors and data collection. Moreover, the study will focus on assessing the potential of these smart bins in improving recycle rates and contribute to the broader effort to reduce plastic waste by promoting design that aligns with the people's needs alongside the integration of advanced technology to make plastic waste disposal more efficient, engaging, and effective.

B. Statement of the Problem

At the end of the study, the researchers will be able to design and evaluate the functionality of a Smart PET Bottle Trash Bin as Waste Reduction Initiatives.

More specifically it sought to:

1. design a Smart PET Bottle Trash Bin as Waste Reduction Initiatives.
2. construct a working prototype of the smart bin.
3. evaluate the constructed Smart Pet Bottle Trash Bin in terms of:

    a. number of PET Bottles that the bin can store upon reaching full capacity by size.
    b. accuracy of the sensor in correctly identifying PET Bottles.
    c. response time of the sensor-driven detection system.
    d. accuracy of the alarm once the storage is full.

4. compare the constructed Smart Pet Bottle Trash Bin with the existing market models.
5. Reliability
6. Durability
7. Cost-Analysis

It is therefore hypothesized that the constructed Smart Pet Bottle Trash Bin can be an alternative for PET Bottle segregation to encourage proper disposal.

C. Significance of the Study

This research aims to benefit the following:

- **Bottling Manufacturers** - The Bottling Manufacturers may benefit from the study by gaining access to cleaner, sorted PET Bottles that support their recycling targets and Extended Producer Responsibility (EPR) compliance.
- **DENR (Department of Environment and Natural Resources)** - The DENR may benefit from this study by using its findings to guide environmental policies, promote sustainable practices, and support waste reduction programs.
- **Future Researchers** - Future Researchers may benefit from this study by using it as a reference for innovations in sustainable design, smart technology applications and circular economy models.

- **Junkshops** - Junkshops may benefit from this study by acquiring higher-quality PET Bottles that are easier to sort and more profitable to process.
- **Learners** - The learners may benefit from this study by gaining insights into sustainable waste management and smart environmental technologies, enriching their education.
- **LGU (Local Government Units)** - The LGU may benefit from this study by improving waste management systems though smarter segregation, leading to reduced landfill waste and better policy implementation.
- **NGO (Non-Governmental Organizations)** - The NGOs may benefit from this study by using it to support environmental advocacy, promote community engagement, and advance zero-waste initiatives.
- **PET bottle consolidators** - PET consolidators may benefit from this study by accessing better quality pre-sorted PET materials, enhancing operational efficiency and supply chain reliability.
- **Recyclers** - The recyclers may benefit from this study by receiving cleaner PET inputs, improving processing efficiency and output quality.

D. Definition Of Terms

- **Polyethylene Terephthalate (PET)** - A sort of resin and polyester, it is commonly known for its durability, thermal stability, gas barrier properties, transparency, lightweight, unbreakable and reusable characteristics (The Waste and Resources Action Programme, 2020).

- **Waste Reduction** - Application of minimizing the use of material and energy to lessen the waste and protect natural resources (Encyclopedia.com, 2018).
- **Consolidators** – A company that purchases specific goods or services from various sources and then sells them to consumers. (Cambridge Dictionary, 2025).
- **Functionality** - The feature of being effective, suitable, and functional for its intended use (Cambridge Dictionary, 2025).
- **Smart Bin** - Smart bins are technologically advanced waste bins that use sensors, connectivity, IoT capabilities and data analytics to improve waste management and recycling; with a goal that is to reduce landfill waste by making the collection and recycling process more efficient (Lettieri, 2023).
- **Microcontroller** - It is a device that uses software to allow interaction with external hardware. Electronic devices such as screens, speakers, lights, sensors, actuators, and other hardware can be linked to such as an Arduino or ESP32 (Hinton, 2024).
- **Sensors** - Sensors are devices that convert physical phenomena into electrical signals that a microcontroller can read and process, acting as the "eyes" and "ears" of a microcontroller system. Sensors detect changes in the environment and collect signals, which are then processed by microcontrollers (Javaid et al., 2021).
- **Recycling -** To treat something like liquid waste, glass, or cans through a series of processing steps so that its material can be recovered and used again by people (Cambridge Dictionary, 2025)
- **Plastic Waste** - Any plastic material whether made naturally or synthetically that has been thrown away after being used in homes or industries (European Environment Agency, 2025)

- **Waste Management** - The full set of activities needed to handle waste from the moment it's created until it's properly disposed of or recycled. This includes everything from gathering and moving trash to treating it, recycling it, and overseeing what comes from homes, businesses, and factories. (CO2Action Sustainability Glossary, 2020).

E. Scope and Limitation

This study will focus on making a Smart PET Bottle Trash Bin prototype that will use an Arduino Uno microcontroller; specifically, an Arduino R3; together with the aid of different sensors, for it to detect and monitor PET bottle waste. The bin's body will be made out of recycled metal sheet and steel matting. The study will only cover PET bottles and will not include other types of plastic or general trash. These bottles will be detected and examined by the scanning system which will collect data depending on their size. The study will only be limited to working with PET Bottles. The prototype will include the minicomputer, microcontroller, and sensors, which will be powered by the Lithium-Ion batteries. Testing will be done in a controlled area to check how well the bin detects bottles and records data. The study started to take place in July 2025 in a chosen school, and the results will be used to see how effective the bin is in recognizing PET bottles, recording waste, and helping with eco-friendly waste management.

Chapter 2

REVIEW OF RELATED LITERATURE

Polyethylene Terephthalate (PET)

Polyethylene Terephthalate (PET) traces its origins to 1941, when Whinfield and Dickson of the Calico Printer's Association patented the material based on the earlier polymer studies of Wallace Carothers. Their work led to the creation of Terylene, the first polyester fiber. PET later expanded into packaging applications, especially after Wyeth patented PET bottles in 1973 for pharmaceutical use (Johnson, 2020).

PET is a linear thermoplastic polyester formed through the condensation of terephthalic acid (TPA or PTA) and ethylene glycol (EG) (Benyathiar et al., 2022). Its cooling behavior determines its structure: rapid cooling results in an amorphous, transparent plastic, while slower cooling or cold drawing produces semicrystalline material. PET is widely processed through extrusion, blow molding, and injection molding, and is valued for its strength, toughness, abrasion resistance, chemical stability, and suitability for high-pressure applications like carbonated beverage bottles (Sin & Tueen, 2023).

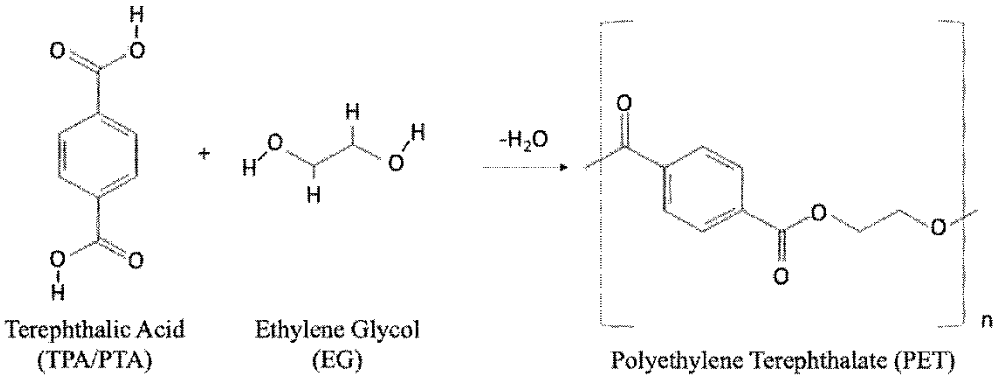


Figure 1. *Chemical reaction between TPA and EG, forming PET*

Despite its favorable properties, the widespread use of PET has intensified global waste management challenges. Inadequate disposal practices lead to significant PET accumulation in landfills and ecosystems. Recent studies emphasize the need for cost-effective, sustainable recycling technologies to support circular economy models (Joseph et al., 2024).

Plastic Waste

Plastic waste appears across all environments and in a wide range of sizes, from large microplastics to progressively smaller meso-, micro-, and nanoparticles formed through the fragmentation and weathering of larger items (Jakubowicz et al., 2021; Li et al., 2016). The global rise in plastic pollution is primarily driven by the substitution of traditional materials with plastics, rapid population growth, and increased engagement in consumer-oriented lifestyles. Urbanization further accelerates waste generation, as dense city populations tend to consume more resources and produce higher volumes of disposable plastics (Kedzierski et al., 2020).

The Philippines produces a large amount of plastic waste each year, but the recycling efforts are still minimal. The World Bank's Market Study on Philippines Plastics Circularity (2021) indicates that around 28% of essential plastic resins, like PET, are recycled, while most plastic waste is either poorly managed, sent to landfills, or released into the environment. This inadequate recovery rate highlights significant deficiencies in collection and segregation processes, resulting in considerable resource loss and lost economic prospects in the plastics value chain.

Smart Bin

A waste-management study utilizing IoT technology developed a smart bin prototype employing an Arduino Uno microcontroller, a Wi-Fi (or GSM) module, and ultrasonic sensors to track waste levels instantly. The system delivered ongoing waste-level information to a central server, facilitating improved collection schedules and reducing unnecessary manual inspections—showing that microcontroller-driven smart bins can greatly lessen human intervention while enhancing efficiency (Abba & Light, 2020; Srivastava & Venkat, 2023).

A recent research paper called “Innovative AIoT Solutions for PET Waste Collection in the Circular Economy Towards a Sustainable Future” suggests a collection system targeting PET that integrates IoT technology with AI image-recognition algorithms to detect plastic bottles and categorize them for recycling. The system identifies bottles independently of color or state and tracks fill levels and collection status through a cloud-based dashboard — showcasing that the combination of sensors, microcontrollers, and AI can facilitate operational, automated PET collection at a residential or community level (Rosca & Stancu, 2025).

In a pertinent case, a prototype of a “Smart Recycling Bin” was created utilizing an embedded system (such as Raspberry Pi) along with machine-learning driven waste categorization. The authors indicate approximately 92.1% overall accuracy in distinguishing various waste types (plastic, glass, metal, organic, etc.), incorporating real-time data communication with waste-management agencies — confirming the viability of smart sorting bins that can minimize contamination and enhance recycling efficiency (Ziouzios & Dasygenis, 2019; Arthur, Shoba & Pandey, 2024).

Rianmora et al. (2023). developed an automated separation mechanism using either microcontroller-based or PLC-based control units. While the system effectively sorted bottles by transparency, the authors recommend adding pattern-recognition features for color and shape detection, as well as evaluating AC vs. DC motor performance for conveyor-based sorting.

Muyunda and Ibrahim (2017) developed a smart waste-bin fill-level monitoring system that incorporated an Arduino microcontroller, a tilt sensor for orientation detection, a level sensor, a real-time clock module, and a web server to receive data from the sensor unit.

Sensors

According to Javaid et al., (2021) & GeeksforGeeks (2025) a sensor is a device or component that detects changes or events in its surroundings and sends that information to other electronics, usually a computer processor. It takes a physical effect and turns it into a measurable digital signal that can be shown, read, or further analyzed. Researchers and specialists classify sensors in several ways:

Classification of Sensors:

Based on Power Requirement

1. Active Sensors - Type of sensors that need an external power source or excitation signal in order to operate.
2. Passive Sensors – Kind of sensors that do not need any external power supply and can produce an output response on their own.

Based on Output Type:

1. Analog sensors - They generate an output signal, usually voltage, current, or resistance, which varies in proportion to the measured quantity.
2. Digital sensors - They provide output data in a discrete or digital form.

Types of Sensors:

1. Temperature sensors - These are used to monitor the temperature of devices in industrial applications. They measure temperature in air, liquids, or solids. Temperature sensors can

be either analog or digital. In an analog temperature sensor, changes in temperature cause changes in a physical property such as resistance or voltage. The LM35 is a well-known example of an analog temperature sensor. In a digital temperature sensor, the output is a discrete digital value. The DS1621 is an example of a digital sensor that provides 9-bit temperature data.

2. Accelerometer sensors - These sensors measure the rate of change of velocity and provide the magnitude of acceleration. The ADXL335 accelerometer sensor gives analog voltage readings for three axes (X, Y, and Z). Accelerometers are commonly used in car electronics, ships, and agricultural machines.
3. Alcohol sensors - These sensors are designed to detect the presence of alcohol. They are commonly used in breathalyzer devices to determine whether a person has consumed alcohol. Law enforcement often uses breathalyzers to identify cases of drunk driving.
4. Radiation sensors - These sensors detect the presence of alpha, beta, or gamma radiation and send signals to counters or display devices. They are commonly used for radiation surveys and for counting samples.
5. Position Sensors - Are electronic devices that detect the position of components such as valves, doors, and throttles, and send signals to control or display systems. Their key specifications include sensor type, function, measurement range, and features unique to each type. They are widely used in any application that requires positional data. One common example is the string potentiometer, often called a “string-pot.”
6. Gas Sensors - Sensors that identify and measure the concentration of gases present in the air or a specific environment.

7. Torque Sensors - Sensors designed to measure rotational force (torque) and are often used to determine the speed or power of rotating machinery.
8. Optical Sensors - Also called photosensors, these detect light across ultraviolet, visible, and infrared ranges. They are commonly used in robotics, smartphones, and media devices like Blu-ray players.
9. Proximity Sensors - Sensors that detect the presence or distance of an object without physical contact. They are used in elevators, vehicles, parking systems, robotics, and many other setups.
10. Touch Sensors - Devices that sense physical contact on a surface. They are widely used in touchscreens, trackpads, elevators, robotics, and automatic dispensers.
11. Image Sensors - Sensors used for tasks such as measuring distance, recognizing patterns, checking colors, and capturing motion. They support applications in 3D imaging, broadcasting, security, automotive systems, biometrics, medical equipment, and machine vision.

Ultrasonic distance sensors are extensively verified for monitoring fill levels in smart-bin systems: comparative field and laboratory studies indicate that ultrasonic sensors deliver dependable, consistent measurements of waste depth and are ideal for route optimization and overflow prevention in urban applications (Brouwer et al., 2023). Although accuracy varies based on the geometry of bins and the type of waste, the available evidence indicates that ultrasonic sensing is a cost-efficient primary technique for automated fill-level assessment in intelligent waste solutions.

Integrating load-cell and ultrasonic sensors improves detection accuracy by combining mass and volume data. Weight sensors capture the mass of low-profile but heavy waste, while ultrasonic sensors measure fill level. Together, they reduce false alerts caused by irregular shapes and provide more reliable fullness estimates, leading to fewer missed collections and better overall performance (Sidhu et al., 2021; Maus, 2024).

Recycling

Research indicates that the quality of recycled PET is significantly influenced by the purity of the collected materials. Hopewell et al. (2020) highlight that effective sorting at the source is the key element affecting the economic feasibility of PET recycling. They determine that technologies facilitating cleaner PET capture can directly improve circularity initiatives throughout the plastic value chain.

Recent life-cycle evaluations indicate that recycling PET in circular-economy frameworks greatly reduces environmental effects. Chairat and Gheewala (2023) discovered that closed-loop and open-loop PET recycling decrease greenhouse-gas emissions and resource consumption by more than 60% relative to virgin PET, particularly when elevated collection and recycled-content rates are sustained. Research on plastic-waste value chains similarly emphasizes that efficient upstream approaches—like enhanced sorting and recycling systems—are vital for reducing material loss and boosting the value of retrieved plastics, reinforcing the demand for integrated collection solutions such as sensor-equipped smart bins (Johansen et al., 2022; Albiter et al., 2022).

Polyethylene terephthalate (PET) is the primary resin employed for single-use beverage containers due to its durability, lightweight nature, and transparency; however, its extensive use has generated significant amounts of post-consumer PET that strain current waste management systems and fuel interest in more valuable recycling pathways (Benyathiar, 2022). Recent assessments highlight innovations in mechanical, chemical, and biological PET recycling—such as depolymerization and enzymatic methods—that may enhance circularity if dependable feedstock sources and collection systems are established (Benyathiar, 2022; Joseph, 2024).

Types of Recycling:

1. Mechanical recycling - a widely used method globally, where waste materials, like plastics from industrial, domestic, or commercial sources, are transformed into new products without altering their chemical composition. This process gives old materials new life, reducing waste and conserving resources.
2. Energy Recycling - a process that converts plastics into thermal and electric energy by burning them, releasing heat that's used as fuel. This method provides an alternative way to manage plastic waste while generating energy.
3. Chemical Recycling - a complex process that involves breaking down plastics and modifying their chemical structure through reprocessing. The resulting product is a raw material that can be used in various industries or as a base input to manufacture new plastic products, offering a versatile and sustainable solution for plastic waste management.

Microcontroller

Microcontrollers (e.g. Arduino / Arduino Uno, or similar microcontroller-based platforms) are widely used in smart waste-bin prototypes as the embedded “brain” that reads sensor data and automates bin-management tasks. A prototype by Ilyas et al. (2021) described in the paper IoT-based Smart Garbage Monitoring uses an Arduino (or NodeMCU) microcontroller together with an ultrasonic sensor to measure dustbin fill levels and send those readings via IoT to a mobile application dashboard—enabling real-time monitoring of garbage levels and reducing reliance on manual checking.

Similarly, the study of Abba & Light (2020) demonstrates a waste-bin prototype built with an Arduino microcontroller, ultrasonic sensors, and a Wi-Fi module — the system periodically detects waste level (empty / half-full / filled) and transmits status data to a central server for remote waste monitoring/control.

Other researchers expand on this design: as seen in the paper Smart Dustbin Monitoring System using Arduino UNO (2023), the Arduino-based embedded system is shown to reliably manage dustbin-level detection and automation, proving that microcontroller-backed smart bins are feasible and effective in "real world-type" waste management settings (Dr. Sudha et al., 2023).

Waste Reduction

Pamudji et al. (2025) demonstrate the waste-reduction potential of such systems through a smart-bin model equipped with a Wemos D1 R32 microcontroller, sensors, and a real-time dashboard that tracks bin capacity. Their design minimizes unnecessary collection trips and ensures that waste is removed only when bins are close to full, reducing fuel use, manpower, and operational inefficiencies.

Field and conference research further highlights that bins equipped with networked sensors—such as fill-level, gas, and location modules—enable optimized waste-collection routes that significantly reduce unnecessary fuel consumption and operational costs. This efficiency not only minimizes the environmental footprint of collecting vehicles but also ensures faster removal of waste before it becomes scattered or contaminated (Raju et al., 2024).

In addition, studies on bottle-specific detection and reverse-vending systems using ESP32 or ESP32-Cam with machine-learning models show that smart collection points can be designed to capture PET bottles more efficiently and prevent them from entering mixed waste streams. By improving the recovery rate of PET at the source, these technologies strengthen circular-economy initiatives, reduce plastic leakage into the environment, and support cleaner recycling processes—further advancing waste-reduction efforts (Nugraha et al., 2025).

Lithium-Ion Batteries

Lithium-ion (Li-ion) batteries are the dominant rechargeable battery technology in consumer electronics, power tools, e-bikes and electric vehicles because of their high energy density and long cycle life. Their growing use increases the importance of understanding their materials, configurations, safety risks, and end-of-life handling — issues directly relevant when designing waste-collection systems (e.g., bins that collect used Li-ion packs or cells) (Nasajpour-Esfahani et al., 2024; Gao, Lan, Yin, & Liu, 2025).

A Li-ion cell consists of an anode, cathode, separator, electrolyte, and current collectors. During discharge, lithium ions move from the anode to the cathode through the electrolyte and separator while electrons flow through the external circuit producing current. During charging, an external voltage forces lithium ions back to the anode. Performance and lifetime depend heavily on electrode materials, the solid electrolyte interphase (SEI) that forms on the anode, and the electrolyte composition (U.S. Department of Energy, 2023; Nasajpour-Esfahani et al., 2024).

Common types / chemistries:

1. Anodes - Commercial Li-ion anodes are most commonly graphite (carbon) or related carbonaceous forms (e.g., hard carbon, graphene derivatives). These materials host lithium during charge and are widely used because of good cycle life and coulombic efficiency.
2. Cathodes - Cathode chemistry largely determines energy density, cost, lifetime and safety. The principal commercial cathode types are:

- LCO ($LiCoO_2$) - high energy density but poorer safety and cycle life (used historically in electronics).
- NMC (Li-Ni-Mn-Co oxides) - widely used in EVs and portable power for a balance of energy and power.
- NCA (Li-Ni-Co-Al oxides) - high energy density (used for some automotive packs).
- LMO (Li-Mn_2O_4) - good high-rate capability; often blended with other chemistries.
- LFP ($LiFePO_4$) - lower energy density but significantly better thermal stability and cycle life; increasingly used where safety and long life are priorities (grid storage, some EVs).
- LTO (Li-titanate) - excellent cycle life and safety but lower voltage/energy density.

In relation to this, battery packs may use different cell arrangements depending on the required output. Series connections increase the total voltage of a battery pack by adding the voltages of each cell, but the entire string becomes limited by the weakest cell, making proper matching and balancing essential to avoid over-charge or over-discharge. Parallel connections, on the other hand, increase the overall capacity (Ah) and current capability, although all cells in a parallel group must share similar state of charge and condition to prevent large balancing currents. Most practical battery packs therefore use a series-parallel combination, which requires a Battery Management System (BMS) to monitor cell voltage and temperature, maintain balance, and reduce safety risks associated with mismatched or aging cells (Battery University) (Battery University, 2021).

Programming Languages

Programming languages serve as the essential link between human intent and machine execution, providing a structured means of communicating instructions to a computer. These languages are defined by their syntax (the specific rules for composing statements) and their semantics (the meaning of those statements when executed) (Ramalingaiah, Ujwal, Balamurali, & Kumar, 2017). The primary function of a programming language is to facilitate abstraction, allowing developers to write complex programs without needing to directly manipulate the low-level electrical signals and memory registers of the computer hardware (Alam, 2015).

The evolution of programming languages mirrors the progression of computer science itself, moving from machine-centric instructions to increasingly human-readable constructs. Early computational systems required developers to work with low-level languages, such as Assembly and Machine Code. The shift toward higher-level languages began with FORTRAN, LISP, and COBOL, introducing features that simplified complex processes like loop execution and data management (O'Regan, 2018). This history demonstrates that the development of new languages is not random, but an evolutionary process driven by the need to solve new types of computational problems and to increase programmer productivity, which continues to shape language design today (Al-Shehri, 2020).

Types of Programming Languages:

Programming languages are broadly classified by their level of abstraction from the hardware:

1. Low-Level Languages - These languages are highly specialized and machine-dependent, offering direct control over memory and hardware resources. They are executed faster because they require minimal translation, but they are difficult for humans to write, read, and debug. Machine code (binary instructions) and Assembly language are definitive examples of low-level languages (Ogli et al., 2025).
2. High-Level Languages (HLLs): HLLs are designed to be closer to natural human language, utilizing complex control structures and data types that significantly abstract hardware

details. They rely on compilers or interpreters to translate the code into a form the computer can execute. This abstraction increases programmer efficiency and code portability across different hardware platforms (Muhammad, Rizwan, & Ashraf, 2021).

The utility of a programming language is intrinsically linked to its application domain. For instance, languages such as Python, Java, and C++ are categorized as general-purpose, but their actual use cases vary widely based on their core strengths (Alam, 2015). In the modern context of Machine Learning (ML) and Artificial Intelligence (AI), Python dominates due to its simplified syntax and extensive scientific libraries (e.g., NumPy and TensorFlow). However, for applications requiring maximal speed and resource efficiency, C++ remains an important choice, particularly for developing low-level inference engines and integrating with other high-performance components (Jumaah, Yasin, & Hamed, 2022).

Microcontrollers and embedded systems, which are foundational to areas like robotics and the Internet of Things (IoT), present unique programming constraints due to their limited memory and processing power. The programming languages used must, therefore, allow for explicit and reliable management of hardware resources. C and C++ are overwhelmingly favored in this field because they offer the necessary low-level control to interact directly with hardware registers and provide predictable memory management, which is critical for real-time and resource-constrained operations (Schultz, 2017)

Chapter 3

METHODOLOGY

A. Research Design Criteria

1. Specifications in terms of:
    a. width of the device
    b. length of the device
    c. weight of the device
    d. height of the device
2. Performance in terms of:
    a. number of PET Bottles that the bin can store upon reaching full capacity by size.
    b. accuracy of the sensor in correctly identifying PET Bottles.
    c. response time of the sensor-driven detection system.
    d. accuracy of the alarm once the storage is full.
    e. reliability
    f. durability
3. Labor requirement:

    The researchers constructed the device with the assistance of some experts and professionals such as engineers and programmers.

B. System Design

Figure 2. *Front View*

Figure 3. *Back View*

Figure 4. *Side View*

Figure 5. *Bottom View*

C. Schematic Diagram

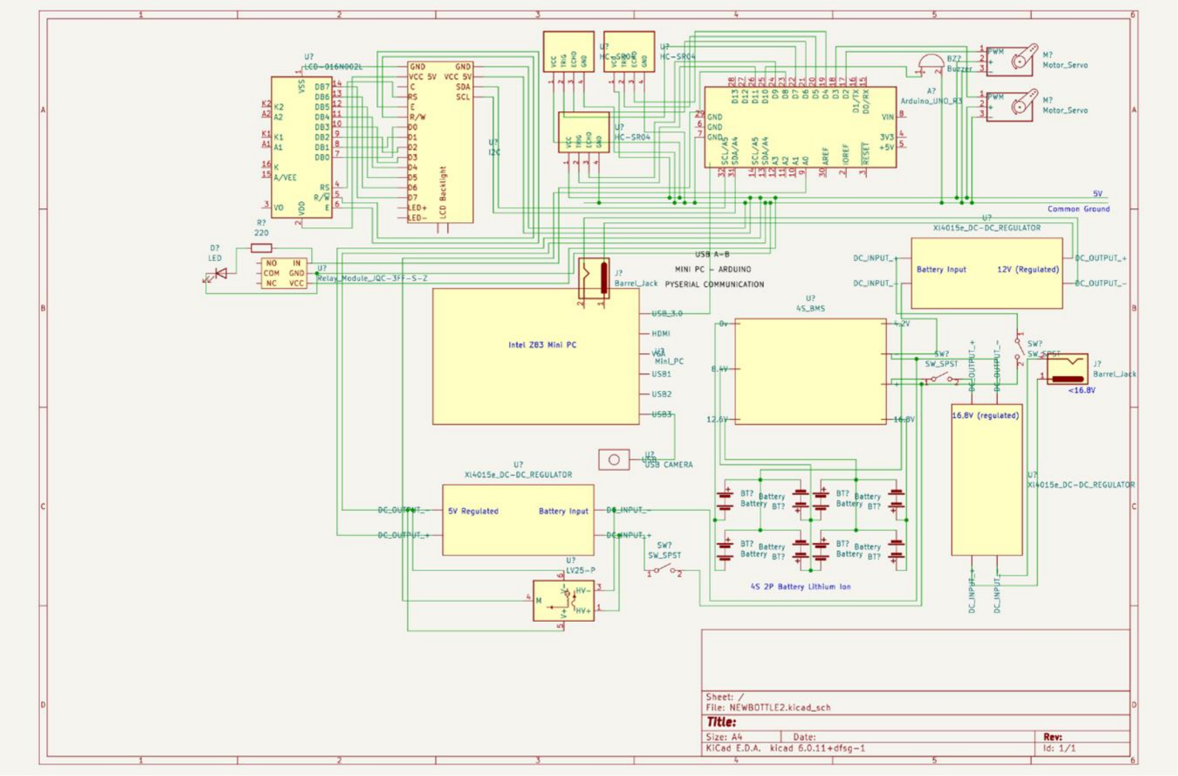


Figure 6. *Schematic Diagram*

D. Block Diagram

The battery will be charged overnight whilst sharing a charge on the Arduino and the minicomputer. During the day, the battery fully powers the machine.

The Arduino will be controlling the different components of the machine. Whilst, the minicomputer runs a program that has bottle reference images that serves as a reference for the camera to identify the material scanned.

An ultrasonic sensor will detect if a bottle is thrown and will start the machine learning program. A camera will evaluate whether the material is a bottle by visually scanning the item inserted based on the images programmed in to the minicomputer.

Inside the trash bin, a storage area stores the bottles, while an ultrasonic sensor at the back detects overfilling. When full, an alarm activates to indicate it needs emptying.

If the program detects a bottle, the acceptor servo opens to let it fall into the bin. If they detect foreign material instead, the servo will not open. This ensures only bottles are collected inside the bin.

E. Materials

The following materials are needed for constructing the Smart PET Bottle Trash Bin.

Materials	Materials
AC–DC Adjustable Charger	Ultrasonic Sensor
Variable Power Supply	Piezo Passive Buzzer
1080P USB Camera	Battery Holder (6 pcs)
Step Down Voltmeter	Relay Switch (5V)
Angle Bar (1.8mm 1" 16ft)	Cart Wheels
Steel Sheet (4x5)	Barrel Jack (Female)
Arduino Uno R3 Atmega	Lithium-Ion Battery
LCD 16x2 + I2C	Screws
Battery Level Capacity Indicator	Soldering Lead
Steel Matting	Wires
SG90 Micro Servo	Mini Computer
BMS	Welding Rod (0.5 kg)

F. Construction Procedure

- ***Gathering of Materials.*** The assembly of the automated Smart PET Bottle Trash Bin commenced with the procurement and inspection of necessary components. The control system is centered around an Arduino UNO R3 and a Minicomputer, supported by a sensor array consisting of three ultrasonic sensors, a passive buzzer, and two MG996R servo motors. Power is supplied by a custom 18650 Lithium-Ion battery pack regulated by a BMS and three variable step-down converters. The physical chassis was fabricated from industrial-grade steel sheets and angle bars, housing two 50L roller-drawer bins and a 13L storage unit for sorted waste.
- ***Fabrication of the Main Frame.*** The skeletal frame was constructed using angle bars cut into specific measurements: twelve pieces at 0.75 meters, four at 1 meter, two at 0.25 meters, and two at 0.63 meters. Two square bases were formed using the 0.75-meter bars and connected vertically using the 1-meter bars to create the main rectangular body.

Another square frame was built for the upper head section. The 0.25-meter bars were installed as rear vertical supports, while the 0.63-meter bars were attached diagonally to create the inclined design. All parts were riveted securely to ensure structural stability.

- ***Installation of Steel Panels.*** Steel sheets were cut according to the dimensions of the frame and riveted onto the sides and back of the structure. The front and top sections were left open to allow installation and access to electronic components.
- ***Electrical Wiring and Power System Installation.*** Wires were soldered together to achieve the required lengths and connected to their designated pins on the Arduino and other modules. The battery pack was configured in a 4S2P (four-series, two-parallel) arrangement and connected to the BMS. Three step-down voltage regulators were connected to the BMS output: one set to 16.8V at 2A for charging, one adjusted to 12V for the Minicomputer, and one calibrated to 5V to power sensors and modules. A dedicated fail-switch was installed for each regulator line for safety. All electronic components were housed inside the 13L storage box, with separate holes drilled for power and data cables to reduce interference. Components were secured with screws or adhesives and organized using nylon cable ties before mounting the box inside the steel frame.
- ***Construction of the Sorting Chute.*** A 24L plastic storage box was modified to serve as the sorting chute. A rectangular section measuring approximately 9 cm by 10 cm was marked and cut to create a trapdoor mechanism. Hinges were attached to allow movement, and plastic stoppers were installed to prevent inward collapse. Openings were drilled to install ultrasonic sensors and servo motor linkages. A servo-sized slot was cut at the center of the chute, and the servo motor was mounted securely. The completed chute assembly was then riveted firmly onto the main frame.

- ***Fabrication of the Retrieval Bin.*** An inner storage bin frame measuring 0.29m x 0.20m x 0.76m was constructed using angle bars. Steel sheets were attached to the sides and bottom while leaving the top open. Roller-drawer slides were installed and secured with rivets to allow smooth retrieval. The bin was then mounted inside the main chassis.
- ***Installation of External Components and Finishing.*** Openings were cut into the steel panels to mount the LCD screen and charging port securely. A roof hatch was fabricated above the electronics compartment and attached using hinges to serve as a maintenance access door. Finally, the exterior of the bin was painted according to the chosen design, ensuring that all electronic components, sensors, and the LCD screen were properly covered and protected during the painting process.

G. How does the device work?

The Smart PET Bottle Trash Bin activates whenever a PET bottle of various sizes (such as 250 mL, 500 mL, or 1 L) is inserted into the entrance slot. The system is designed to charge its battery during the night, allowing it to operate fully on battery power throughout the day until the charge is depleted. A mini-computer handles the camera-based detection system, determining whether the inserted item is a PET bottle or a foreign object. The Arduino functions as the microcontroller, communicating with the minicomputer and converting its data into control signals for the system’s components. The bin integrates several sensors and components, including ultrasonic sensors, servo motors, LED indicators, and a small text-based LCD screen, all working together to support its automated functions.

H. Steps in Evaluation

- ***Gathering of instruments for testing.*** The instrumentation that the researchers used will all come from their respective houses, which are the Stopwatch, Weighing Scale, Measuring Tape, and Digital Multi-Meter.
- ***Measuring the width of the device.*** The researchers measured the width of the device in centimeters (cm) with the use of a measuring tape.
- ***Measuring the length of the device.*** The researchers measured the device in centimeters (cm) with the use of measuring tape.
- ***Measuring the weight of the device.*** The researchers measured the device in kilograms (kg) with the use of a weighing scale.
- ***Measuring the height of the device.*** The researchers measured the device in centimeters (cm) with the use of measuring tape
- ***Measuring the number of PET Bottles that the bin can store upon reaching full capacity by size.*** The researchers measured the bin's storage capacity by inserting uniform-sized PET bottles one at a time until it was full, then counting the total bottles for each size.
- ***Measuring the accuracy of the sensor in correctly identifying PET Bottles.*** The researchers tested sensor accuracy by inserting PET bottles and foreign materials and noting whether the system correctly identified each one.
- ***Measuring the response time of the sensor-driven detection system.*** The researchers measured the response time of the detection system through the use of stopwatch in terms of minutes.

- ***Measuring the accuracy of the alarm once the storage is full.*** The researchers measured the accuracy of the alarm by repeatedly filling the bin with PET bottles until full and checking if the LCD and LED indicators are activated at the correct time.
- ***Measuring the reliability of the device.*** The researchers measured the reliability of the device through continuous testing for 1 day.
- ***Measuring the durability of the device.*** The researchers measured the durability of the device by subjecting it to a drop test.

I. Instrumentation

- Stopwatch

The stopwatch is used by the researchers to measure the response time of the sensor driven detection system in terms of minutes.

- Digital multi-meter

The digital multi-meter used by the researchers to measure the current and voltage of the battery used by the Smart PET Bottle Trash Bin per unit time.

- Measuring tape

The measuring tape is used by the researchers to measure the width, height and length in terms of centimeters (cm).

- Weighing Scale

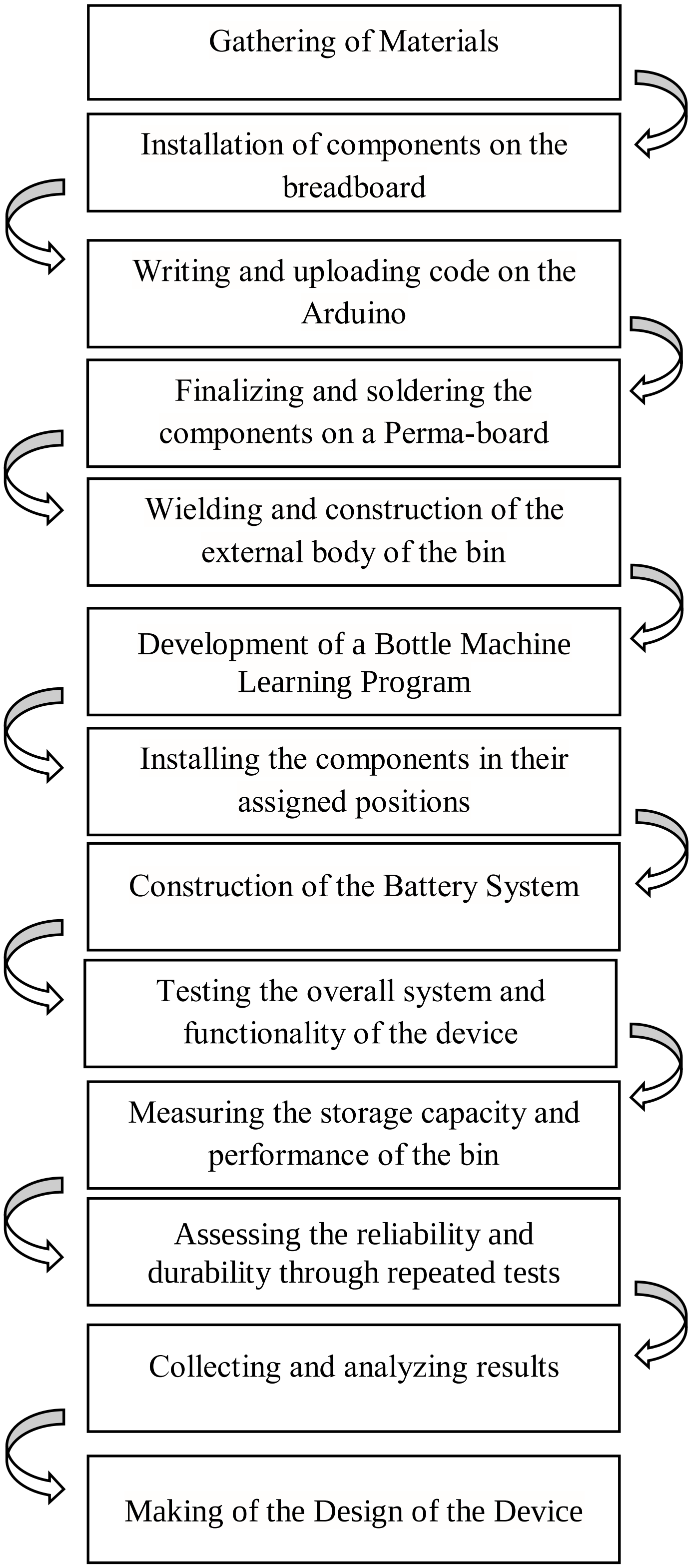
The weighing scale used by the researchers to measure the weight of the device in terms of kilograms.

J. Cost Analysis

Materials	Quantity	Amount	Total Cost
AC-DC Adjustable Charger	1	₱290.00	₱320.00
Step Down Regulator DC	3	₱172.00	₱526.00
Angle Bar (1.8mm 1" 16ft)	3	₱170.00	₱510.00
1080P USB Camera	1	₱150.00	₱210.00
Steel Sheet (4x5)	4	₱150.00	₱588.00
Minicomputer	1	₱150.00	₱150.00
1/2-liter black paint	1	₱125.00	₱125.00
Arduino Uno R3 Atmega	1	₱120.00	₱120.00
SM996R Servo	2	₱120.00	₱240.00
Soldering Lead	1	₱100.00	₱100.00
Storage box 24L	1	₱100.00	₱100.00
Cartwheels	2	₱95.00	₱190.00
LCD 16x2 + I2C	1	₱90.00	₱90.00
Steel Matting	1	₱75.00	₱70.00
Steel bar	1	₱75.00	₱75.00
BMS	1	₱64.00	₱65.33
Welding Rod (0.5kg)	1	₱56.00	₱57.33
Piezo Passive Buzzer	1	₱50.00	₱50.00
Battery Holder (6Pcs)	1	₱50.00	₱50.00
Screws	1	₱50.00	₱50.00
ULTRASONIC SENSOR (1)	3	₱45.00	₱135.00
Relay Switch 5V	2	₱39.00	₱78.00
Rivets x20	3	₱30.00	₱90.00
Voltage Sensor 25V	1	₱20.00	₱30.00
masking tape	2	₱20.00	₱40.00
Hinge	4	₱20.00	₱80.00
Door handle	1	₱20.00	₱20.00
Barrel Jack (Female)	1	₱11.00	₱11.00
electrical tape	1	₱9.00	₱9.00
Lithium Ion Battery	8	₱0.31	₱2.50
Wires	1	₱-	₱-
Storage box 13L	1	₱-	₱-
LED strip	1	₱-	₱-
220ohm resistor	1	₱-	₱-
TOTAL			₱4,182.17

Table 1. *Cost Analysis*

Procedural Design



Chapter 4

RESULTS AND DISCUSSION

The researchers designed, constructed, and evaluated a smart PET bottle trash bin that detects PET bottles using an Arduino Uno and minicomputer.

The functionality and performance of the system were assessed, and the results obtained demonstrate its effectiveness when applied to a smart PET bottle trash bin capable of detecting PET bottles.

Table 2 shows the storage capacity of the smart PET bottle trash bin based on different PET bottle sizes. The bin was approximately able to store 1,151 small (300 mL) bottles, 236 medium (500 mL) bottles, and 85 large (1 L) bottles before reaching full capacity. When bottles of mixed sizes were inserted, the bin accommodated around 220 bottles. Furthermore, the results indicate that smaller bottles allow more efficient use of space inside the bin. As bottle size increases, the number of bottles that can be stored decreases. This suggests that the bin is most effective in environments where small to medium PET bottles are commonly disposed of.

Table 2. *Storage Capacity by Size*

PET Bottle Sizes	No. of Bottles Stored until Full
Small (e.g. 300mL)	1151
Medium (e.g. 500mL)	236
Large (e.g. 1L)	85
Mixed Random	220

Results from Table 3 show that the sensor successfully detected PET bottles in all five trials. Each trial was marked as “Yes” for correct detection and rated as accurate. This indicates a high detection accuracy, demonstrating that the sensor is highly reliable in identifying PET bottles consistently in five trials. The consistent performance suggests that the detection mechanism is effective and suitable for practical application in waste segregation systems.

Table 3. *Sensor Accuracy in Identifying PET Bottles*

Trial No.	**Correctly Detected (Yes/No)**	**Remarks (Accurate/Not)**
1	Yes	Accurate
2	Yes	Accurate
3	Yes	Accurate
4	Yes	Accurate
5	Yes	Accurate
Total Correct Detection	5	Accurate

Furthermore, table 4 presents the recorded response times of the sensor across five trials. The response times ranged from 1.76 seconds to 5 seconds, with an average response time of 3.05 seconds. This indicates that the system reacts within a reasonable time frame after detecting a bottle. Although some variation exists, the overall performance remains efficient enough for real-time waste disposal operations.

Table 4. *Response Time of the Sensor-Driven Detection System*

Trial No.	**Time Recorded(seconds)**
1	5
2	2.33
3	4.38
4	1.76
5	1.78
Average Response Time	**3.05**

The results show that the full-bin alarm system performed accurately during testing. In all trials where the bin was full, the alarm was activated correctly in all three trials when the bin was full. There were no instances where the alarm failed to activate. This result confirms that the alarm system is dependable in notifying users or maintenance personnel when the bin has reached its maximum capacity. Accurate alarm activation helps prevent overflow and ensures timely collection, contributing to proper waste management practices.

Table 5. *Accuracy of the Full-Bin Alarm*

Trial No.	**Bin Full (Yes/No)**	**Alarm Activated (Yes/No)**
1	Yes	Yes
2	Yes	Yes
3	Yes	Yes
Correct Alarm Activations	**3**	**3**

Table 6 evaluates the system's reliability when exposed to non-PET waste materials. The system operated correctly for paper, plastic wraps, paper cups, and other materials such as metals and wood, indicating good filtering and rejection capabilities. However, the system failed to operate correctly when detecting cans, suggesting a limitation in distinguishing certain long and cylindrical objects from PET bottles. This highlights a potential area for improvement, particularly in refining material recognition to prevent incorrect detections but still the trash bin's functionality and purpose is still dependent on the user's proper practice of waste segregation.

Table 6. *Reliability Test with Respect to other types of Trash*

Type of Trash	**System Operated Correctly (Yes/No)**
Paper	Yes
Cans	No
Plastic Wraps	Yes
Paper Cups	Yes
Others (e.g. Metals, Wood, etc.)	Yes

For durability, the repeated use test evaluated the system's ability to withstand continuous operation by inserting 10, 20, 30, and 40 bottles. The results show that no malfunctions were observed throughout all testing levels. This indicates that the mechanical components and sensor system of the Second Life Bins are reliable and capable of enduring repeated daily use. The absence of performance issues suggests that the bin is suitable for long-term operation in real-world environments, particularly in locations with frequent PET bottle disposal.

Table 7a. Durability (*Repeated Use Test)*

No. of Bottle Insertions	Malfunction Observed (Yes/No)
10 Bottles	No
20 Bottles	No
30 Bottles	No
40 Bottles	No

The load and pressure test assessed the structural strength of the bin under varying levels of physical force. Under light pressure (1 kg), no deformation was observed, and the bin remained fully functional, demonstrating adequate structural stability under normal handling conditions. However, under moderate pressure (3 kg), structural deformation was observed, and the system lost functionality. This suggests that while the bin performs well under minimal physical stress, it is vulnerable to heavier loads, which may compromise both its structure and operation. These findings indicate the need for structural reinforcement and stronger materials to improve durability and ensure reliable performance under higher pressure conditions.

Table 7b. Durability (*Load/Pressure Test)*

Test	Applied Load(kilograms)	Deformation Observed (Yes/No)	Functionality (Yes/No)
Light Pressure	1	No	Yes
Moderate Pressure	3	Yes	No

Commercially available smart trash bins typically include features such as automated lid opening, waste level monitoring, and sometimes cloud-based data tracking. However, these systems are often expensive and designed for large-scale commercial use. Based on the comparison, the Second Life Bins offer a cost-effective alternative to existing smart trash bins. While commercial devices may provide advanced features such as IoT connectivity and data analytics, the proposed system focuses on PET bottle detection and waste segregation, which are more relevant to recycling initiatives. The results show that the Second Life Bins effectively balance functionality, reliability, and affordability, making it suitable for localized waste management applications.

Table 8. *Comparison of Second Life Bins and Existing Market Devices*

Feature	Second Life Bins	Commercial Smart Bins
PET bottle detection	Yes	Limited
Waste segregation focus	Yes	No
Full-bin alarm	Yes	Yes
Sensor accuracy	High	High
Cost	Low (~4,100 PHP)	High (15,000–50,000+ PHP)
Ease of maintenance	Easy	Moderate to difficult
Target users	Schools, communities	Malls, smart cities

Chapter 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The findings of the study were summarized as the researchers were able to:

1. design a Smart PET Bottle Trash Bin as a waste reduction initiative.
2. construct a working prototype of the Smart PET Bottle Trash Bin.
3. assess the storage capacity of the smart bin, which accommodated approximately 1,151 small (300 mL) bottles, 236 medium (500 mL) bottles, 85 large (1 L) bottles, and about 220 bottles of mixed sizes.
3. confirm that the sensor consistently and accurately detected PET bottles in all trials conducted.
4. determine that the sensor-based detection system operated with an average response time of 3.05 seconds.
5. verify that the alarm system reliably activated once the bin reached full capacity.
6. examine the system’s reliability when exposed to various types of waste and establish that it successfully filtered most materials except cans.
7. analyze the effectiveness of the smart bin in encouraging proper PET bottle segregation and reducing waste.
8. validate the overall functionality and operational efficiency of the constructed smart bin through testing and performance evaluation.
9. assess the durability of the system through repeated-use testing, which showed no malfunctions, indicating suitability for continuous daily use.

10. analyze the structural strength of the bin, which remained functional under light pressure (1 kg) but showed deformation and loss of functionality under moderate pressure (3 kg).

Conclusions

Based on the results stated, the constructed Smart PET Bottle Trash Bin is effective in detecting, storing, and segregating PET bottles. The device demonstrated reliable sensor accuracy, acceptable response time, dependable alarm activation, and consistent performance during testing. It can be used as an alternative trash bin for PET bottles segregation to encourage proper waste disposal.

Recommendation

Based on the results and conclusions of the study, the following recommendations are suggested:

1. Recyclers, bottling manufacturers, PET bottle consolidators, and junkshops may adopt the Smart PET Bottle Trash Bin to obtain cleaner and pre-segregated PET bottles, improving recycling efficiency, supporting Extended Producer Responsibility (EPR) compliance, and increasing processing and operational efficiency.
2. Local Government Units (LGUs), the DENR, educational institutions, and NGOs, may use the system and findings of this study as a reference for implementing, promoting, and further developing smart and sustainable waste management solutions that support waste reduction and environmental protection.
3. Future researchers may use this study as a baseline for further research on automated waste segregation, smart bins, and sustainable waste technologies.

4. The detection system may be enhanced by integrating advanced sensors or image recognition technology to improve accuracy and better distinguish PET bottles from similar materials such as cans.
5. Structural reinforcement of the bin is recommended to improve durability and resistance to physical pressure, especially in high-traffic public areas.
6. Additional features such as data logging, wireless communication, and the use of renewable energy sources (e.g., solar power) may be incorporated to improve system efficiency, monitoring, and sustainability.

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APPENDICES

Appendix A: Results

The researchers constructed a fully functioning device as a waste reduction initiative

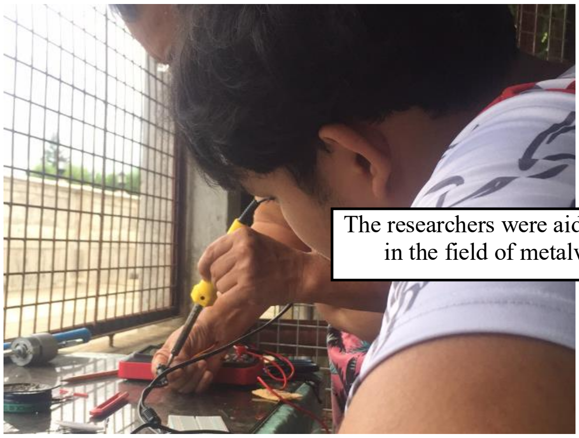
Appendix B: Consultation

The researchers visited experts to consult regarding the electronic mechanisms of the device

Appendix C: Gathering of Materials

The researchers searched for materials at junkshops.

Appendix D: Construction



The researchers were aided with the help of experts in the field of metalworks and construction

Appendix E: Evaluation

The researchers evaluated the functionality of the device.

Appendix F: Researchers

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