WiFi from Waste: Converting Recyclable Materials into Internet Access

A Capstone Project by

Jorell E. Abecia
Airies C. Abuso
Romeo T. Estember Jr.
Rovelle Kate L. Nahial

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APPROVAL SHEET

This capstone project entitled WiFi from Waste: Converting Recyclable Materials into Internet Access, prepared and submitted by *Jorell E. Abecia, Airies C. Abuso, Romeo T. Estember Jr. and Rovelle Kate L. Nahial*, in partial fulfillment of the requirements for the degree Bachelor of Science in Information Technology is hereby accepted.

SALES G. ARIBE JR.,
Capstone Project Adviser

<Chair (CAPSLOCK)>
Chair, Defense Panel

<Panelist 1 (CAPSLOCK)>
Panel Member

<Panelist 2 (CAPSLOCK)>
Panel Member

Accepted and approved for the conferral of the degree Bachelor of Science in Information Technology.

SALES G. ARIBE JR., DIT
Department Head, Information Technology

MARILOU O. ESPINA, DIT
Dean, College of Technologies

DEDICATION

This portion is optional but perhaps you have someone or some people who have inspired you to push on with your studies. A dedication would be a fitting way to acknowledge their impact on your success.

ACKNOWLEDGMENTS

The road to this point in your studies couldn’t have been traveled alone. Along the way, someone somewhere helped you. This is your chance to thank them.

By the way, exercise the liberty to be personal to reflect the sincerity of your gratitude.

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ABSTRACT

Insert your abstract here. This portion is not to be indented and should be clear, concise, and complete. As much as possible, limit the introductory part to a few sentences and make sure that the last sentence reiterates the achievement of the general objective of the research.

1 INTRODUCTION

1.1 Background of the Study

Waste is among the leading issues that organizations and countries are facing in this world. This comprises all things regarded as or declared as unwanted or unusable, including domestic, municipal, and industrial waste (BJYU's, 2023). Presently, over two billion metric tons of waste are generated annually, and this has a very negative impact on the environment (World Bank, 2023). If current practices don't change, this amount might be 3.78 billion metric tons by the year 2050, which is 1.66 billion metric tons more than the current levels of emissions in 2020. Right now, only 62% of waste is collected by the normal methods; the rest is either dumped or burned, with only 19% going through recycling and 30% going to sanitary landfills (Climate Action, 2024). These statistics explain how proper waste collection and recycling have not been properly performed.

Waste collection involves proper accumulation of waste with certain specificity to enhance the recycling process (Waste collection strategy, n.d.). Currently, there is a problem of plastic waste in many countries; it is therefore difficult to control the application of plastic waste (World Bank, 2023). In the Philippines, addressing the methods of waste management through the Ecological Solid Waste Management Act 9003 adopted in 2000 encourages sorting of waste and developing Material Recovery Facilities MRFs (Cuenco-Inocencio, n.d.). Nevertheless, the problem of waste littering is urgent in many local areas. These effects and others worsen these issues and relate to trends of waste disposal, such as discarding litter in public areas and water bodies.

The problem concerning waste is also evident in Malaybalay City. The City Environment and Natural Resources Office (CENRO) has conducted clean-up operations that resulted in the picking up of piles of littered waste. For example, about 3,000 kilograms of the solid waste were retrieved from the waterways, including Sawaga River, Kalawaig Creek, and Caul-Mansikol Creek (Valdez, 2019). In January 2022, on the By-Pass Road, a clean-up resulted in the collection of 700 kilograms of waste, mostly plastic bottles and food containers left behind by motorists (Valdez, 2022). Later in July 2023, another clean-up drive in Sumpong Bridge and from the San Jose-Magsaysay Intersection collected 1,000 kilograms of waste. They include plastic wrappers and bottles (“City ENRO Marks 14th Anniversary,” 2023).

These clean-up operations highlight the persistent issue faced by Malaybalay City's waste management system. The huge amount of waste being sorted and thrown haphazardly in water bodies and on land surfaces necessitates an increase in waste collection services. The municipal CENRO of Malaybalay collected waste management statistics for the year 2023 and discovered the ten barangays that contributed the most to the collection: barangay 3, barangay 4, barangay Imbayao, barangay 7, barangay 10, barangay 11, barangay 2, Kalasungay, San Martin, and Casisang. As a result, barangay 3 was chosen for this study due to the large volume of waste represented and emphasized in Figure 1-1 below.

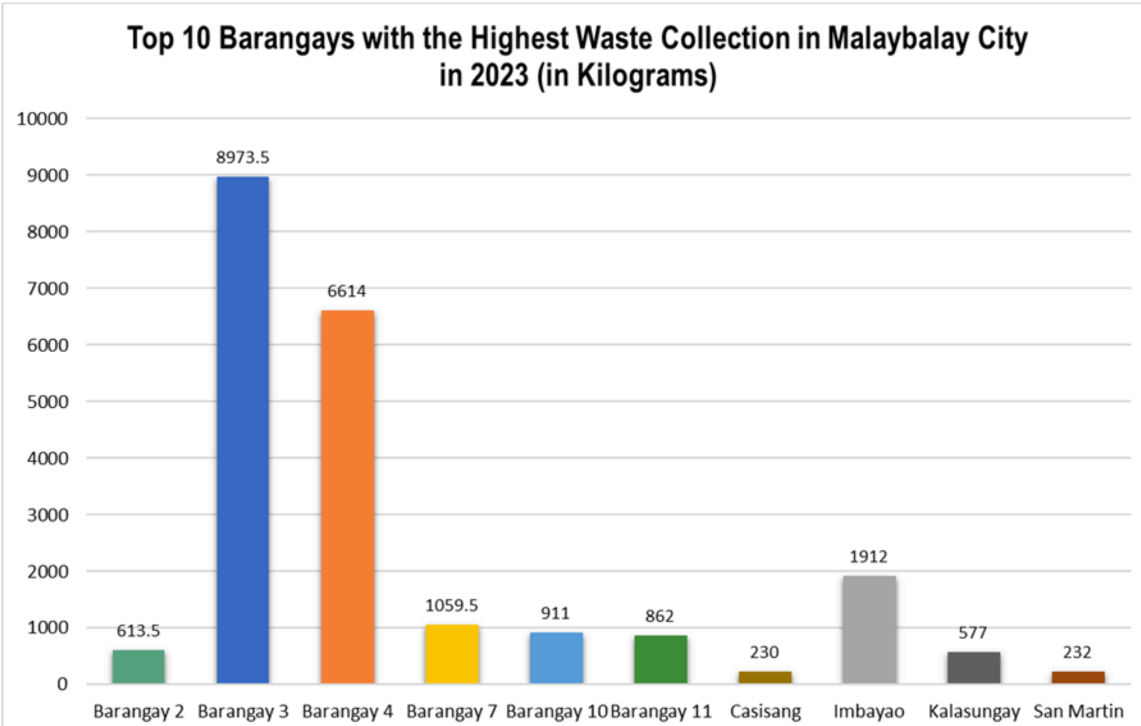

Figure 1-1. Bar Graph of the Top 10 Barangays with the Highest Waste Collection in Malaybalay City in 2023

Based on the MRF Inventory 2023 shown in Figure 1-1, the highest waste collection was in Barangay 3 in Malaybalay City with a weight of 8,973.5 kg. The second highest collection was in Barangay 4, which stands at 6,614 kg, while Imbayao and Barangay 7 collected 1,912 and 1,059.5 kilograms, respectively. Such figures suggest that there is a great need to address waste issues in Barangay 3. Therefore, the capstone project will utilize the power of the You Look Only Once (YOLO) algorithm to improve the solid waste management system of Barangay 3 by detecting and classifying different kinds of waste in real time. This object detection technology is integrated to provide local authorities with internet connection, which enhances waste segregation, optimizes collection, and increases community participation in the cause of environmental sustainability.

Furthermore, the Internet of Things (IoT) and object detection technologies offer innovative solutions to waste management challenges. For example, IoT technologies can measure the level of garbage in many containers in real time, increasing collection efficiency in terms of time and cost (Nordsense, 2023). Object recognition techniques like YOLO, Faster R-CNN, and SSD can scan trash bins and identify the types of waste materials found within, facilitating the sorting and recycling process (Rajkumar et al., 2023). This study analyzes existing and proposed systems, such as "Wifi from Waste: Converting Recyclable Materials into Internet Access," and concludes that the YOLO algorithm has advantages in addressing waste management issues. Its ability to detect in real time promotes more efficient waste collection, which enhances recycling rates. The proposed solution is unique since it combines the quick speed of image processing utilizing the YOLO algorithm with IoT technology in collecting and segregating recyclables.

1.2 Statement of the Problem

Extensive quantities of recyclable waste can cause considerable problems. For instance, the inadequate disposal of waste leads to environmental contamination and disrupts ecosystems. In addition, waste collection initiatives have been implemented across all 46 barangays in Malaybalay City. However, barangay 3 has the highest volume of waste collected among the barangays in Malaybalay City. Enhancing the collection method of recyclable materials and converting it to Internet access provides an innovative solution.

This study aims to address the following key problem: How can YOLO object detection technology be used to improve the collection in Barangay 3 of Malaybalay City and convert this into a system for providing WiFi access to residents?

1. What types and quantities of recyclable materials can be effectively detected and sorted using YOLO technology in Barangay 3's waste stream?
2. How can the collection and processing of recyclable waste be optimized using YOLO-powered systems?
3. What IoT technologies are required to convert the value of collected recyclables into WiFi access for the community?

By addressing these questions, this study aims to explore the application of YOLO in object detection to enhance the collection and sorting method of Barangay 3 in Malaybalay City. This approach creates a flexible, technology-driven solution that turns the value of recyclables into a reliable and accessible internet, contributing to both environmental sustainability and digital inclusion.

1.3 Objectives of the Study

The primary objective of this study is to develop a system that enhances the collection and management of recyclable waste by utilizing the YOLO algorithm for real-time detection, classification, and sorting of waste, while converting recyclable materials into internet access through IoT integration.

Specifically, this study aims to:

1. design an automated waste management system integrated with IoT technologies for optimized waste segregation and collection;

2. detect and classify recyclable waste based on type using YOLO algorithm;
3. assess the accuracy performance of YOLO algorithm when detecting and classifying recyclable waste in terms of:
    a. Mean Average Precision(mAP),
    b. Intersection Over Union(IoU),
    c. Precision,
    d. Recall (Sensitivity),
    e. F1-Score,
    f. Confusion matrix, and
    g. Detection Time (Inference Time)
4. evaluate the effectiveness of the web application based on ISO/IEC 25010:2023 in terms of:
    a. Functional Suitability,
    b. Usability, and
    c. Performance Efficiency

1.4 Significance of the Study

This study explores an innovative approach to incentivize recycling by offering Wi-Fi access in exchange for recyclable materials. This research study aims to improve the waste collection of Malaybalay City, Barangay 3 while simultaneously providing a valuable service. By focusing on common recyclables such as plastic bottles, cans, and paper, the study seeks to promote proper waste collection of the materials within the community. The proposed system in this study will be beneficial to both people and the environment.

For the **City Environmental and Natural Resources Office (ENRO).** This study will provide valuable information on a novel approach to waste management, helping the ENRO develop more effective strategies for promoting recycling in the community. The results can guide policy-making and resource allocation for environmental initiatives.

For **Residents.** This study will help residents understand the importance of proper waste collection and recycling. By participating in the Wi-Fi for recycling program, they will gain practical knowledge about waste management while benefiting from improved internet access. This approach can lead to long-term behavioral changes in recycling habits.

For **Researchers.** The study will contribute to the body of knowledge on innovative recycling incentives and community engagement in environmental initiatives in Malaybalay City Barangay 3. It provides a model that can be analyzed, refined, and potentially applied in other contexts.

For **Junk Shops:** This study will create a partnership with junk shops, allowing the business to actively participate in the community's recycling efforts. By offering discounts or rewards to residents who contribute recyclables, junk shops can enhance its brand visibility and demonstrate a commitment to sustainability.

1.5 Scope and Delimitations

The primary goal of the study is to develop a waste collection and segregation system that offers Wi-Fi in exchange of recyclable materials. The system will utilize Orange Pi 5 and Raspberry Pi 3 camera module 3 to detect and classify recyclable waste based on type using YOLO algorithm. HX711 sensor, on the other hand, will be used to weigh the paper deposited in the system. Additionally, the research is focused on the collection of paper, plastic bottles, and metal and aluminum cans. The system is designed to automatically segregate the cans and plastic bottles. Paper, on the other hand, will be collected separately, with a dedicated space for its storage, and will be processed alongside the other recyclables. Furthermore, paper is chosen for the study because it represents a significant portion of the materials collected through the Eco-Savers program of Malaybalay CENRO. According to the statistics in 2021, 86.14% of the recyclables collected by the local government was paper (City Environment and Natural Resources Office, n.d.). In addition, the MRF Inventory of Malaybalay CENRO in 2023 showed that cans and plastic bottles, particularly mineral plastic bottles, constitute 16% of the total sales of the organization. Out of the 10 classified waste types, these materials were ranked second most profitable recyclables, followed by paper with 13%. Once the waste is collected, it will be turned over to the barangay. Additionally, the purpose of the system is to enhance waste disposal in Barangay 3, Malaybalay City due to its high volume of waste collection. The IoT technology will be used to ease and automate the collection and segregation process of the recyclables. Moreover, the YOLO algorithm will be utilized to identify and categorize the recyclable items. Points will be awarded to users depending on their waste contributions. Cans and plastic bottles are given points based on the quantity provided by the user while the points for paper are calculated using its weight. The users will be able to connect to the internet once they accumulate a certain amount of points. The primary objective of the system is to enhance recycling by offering internet connectivity as a reward, which promotes both responsible waste disposal and increased community participation.

In addition, the study will focus on Barangay 3 due to its high waste collection rate in the MRF inventory in 2023. The research will exclude other waste types such as organic or non-recyclable items. Moreover, the system will automatically segregate plastic bottles and cans, while paper will be collected separately. The system's primary function is to facilitate waste collection and segregation, and provide the materials to the appropriate authorities for further processing.

2 REVIEW OF RELATED LITERATURE

This chapter reviews related literature and existing systems in the realm of waste collection and management. It discusses waste generation issues and emphasizes the importance of effective solid waste management. It also explores the role of IoT technologies and object detection algorithms, particularly YOLO, in enhancing waste collection efficiency. In addition, the chapter examines existing systems and compares its strengths, weaknesses, and the technologies it utilized. By exploring these systems and algorithms, the chapter highlights how innovative technologies can enhance waste collection efficiency and improve overall waste management practices.

2.1 Related Literature

2.1.1 Waste Generation and its Impact on International, National and Local Levels

Waste refers to materials that are unwanted, unusable, and considered to have no value. This includes domestic waste, municipal waste, and industrial waste (BJYU's, 2023). According to Climate Action (2024), over two billion metric tons of unsustainable waste are generated globally each year, polluting ecosystems worldwide. If the current waste management practices continue, total waste generation is projected to reach 3.78 billion metric tons by 2050, a 1.66 billion metric tons increase from 2020. Currently, 62% of global waste is collected at controlled municipal facilities, while 38% is dumped, burned, or discarded improperly. Of the collected municipal waste, only 19% is recycled, and 30% is sent to sanitary landfills, which aim to minimize environmental impact and capture greenhouse gasses from decomposing waste. Moreover, environmental contamination from solid waste mismanagement is a significant global issue, particularly in low-income countries where open dumping and burning are common disposal methods (Ferronato & Torretta, 2019). According to the World Bank (2023), insufficient waste management practices, such as open dumping and burning, intensify the plastic waste crisis, and many countries encounter difficulties in effectively processing this waste.

Furthermore, the Philippines faces a significant plastic pollution problem, with at least 19 rivers, including the Pasig, Tullahan, and Meycauayan rivers, ranking among the top waterways emitting plastic. Many local government units (LGUs) in the Philippines lack adequate waste disposal infrastructure, such as landfill sites and recycling facilities. As a result, dumping and burning have become the primary methods of waste disposal, leading to environmental harm and health risks (Manas, 2023). In addition, solid waste is a major issue in urban areas such as Metro Manila, where problems like improper disposal, poor collection, and inadequate facilities are prevalent (Philippine Solid Waste, 2017). Environment Secretary Maria Antonia Yulo-Loyzaga noted that the Philippines generates approximately 61,000 metric tons of solid waste daily, enough to fill around 37 Olympic-sized swimming pools. Specifically, data from the National Solid Waste Management Commission (NSWMC) reveals that Metro Manila produced about 9,500 tons of waste per day (tpd) in 2020, with projections showing an increase to 10,400 tpd by 2025 (Reyes, 2023). If these issues aren’t addressed, they can cause serious health risks and environmental damage, including water contamination, flooding, air pollution, and disease spread (Philippine Solid Waste, 2017).

Additionally, the global and national problems with waste manifest in Malaybalay City. The Malaybalay City Environment and Natural Resources Office (CENRO) has been spearheading city clean-up drives in recent years and have collected substantial amounts of improperly disposed waste. According to Valdez (2019), approximately 3,000 kilograms of solid waste were collected from various water bodies, including Sawaga River, Kalawaig Creek, and Caul-Mansikol Creek. In addition, a clean-up was conducted along the Malaybalay City By-Pass Road in January 2022. The activity gathered an additional 700 kilograms of waste. This waste largely consisted of plastic bottles, food containers, and utensils and was primarily attributed to littering by passing motorists. Certain areas along the by-pass road have been identified as "hot spots" for open dumping and unsegregated waste, underlining the ongoing waste management problems in the city (Valdez, 2022). Furthermore, Malaybalay CENRO spearheaded another clean-up drive in July 2023 and resulted in the collection of 1,000 kilograms of waste. This waste was collected from Sumpong Bridge to City Nursery and from San Jose- Magsaysay Intersection to Drug Rehabilitation Center. It predominantly consists of plastic wrappers, cellophane, diapers, and plastic bottles (“City ENRO Marks 14th Anniversary,” 2023).

The increase in waste generation on international, national, and local levels is evident. There are two billion metric tons of unsustainable waste produced annually in the world, with projections indicating this figure could rise to 3.78 billion metric tons by 2050. In the Philippines, approximately 61,000 metric tons of solid waste are generated each day, with Metro Manila alone contributing around 9,500 tons per day in 2020. Furthermore, Malaybalay City has witnessed significant waste challenges, as evidenced by clean-up drives that have collected 3,000 kilograms of waste from water bodies and an additional 1,700 kilograms along highways and roads. If these problems remain unresolved, it can lead to serious health risks and environmental harm. Thus, to effectively address these issues, it is crucial to first understand the waste collection strategies employed at international, national, and local levels.

2.1.2 Waste Collection Strategies Across International, National, and Local Contexts

Waste collection is a vital component of an effective municipal solid waste management system. The primary objective of a waste collection strategy is to efficiently and economically gather as much properly sorted waste as possible. This helps facilitate the subsequent sorting and treatment stages, and maximize opportunities for reuse and recycling (Waste collection strategy, n.d.). Furthermore, Extended Producer Responsibility (EPR) plays a crucial role in reinforcing waste collection strategies worldwide. It is a regulatory system that was first implemented by the European Union (EU) (Resource Center, n.d.). This policy holds manufacturers accountable for the environmental impact of their products after they are used. It enhances waste management systems by requiring producers to actively participate in the waste collection process of their own products, which leads to better sorting, recycling, and sustainable practices (Sin & Tueen, 2023). For instance, EPR legislation in India places the responsibility on producers and manufacturers to manage the waste generated from their products, such as plastic packaging. The manufacturers in the country must collect, reuse, or recycle their product wastes instead of sending it to landfills (Lama, 2024).

Additionally, the Philippines has also adopted several key waste collection strategies. According to Caelian (2023), the key waste collection strategies in the Philippines include the Build-Build-Build initiative and the Ecological Solid Waste Management Act. The Build-Build-Build initiative has led to the development of numerous infrastructures. It highlighted the need for sustainable construction and demolition waste management (SCDWM) strategies to reduce environmental impact. The Ecological Solid Waste Management Act of 2000 (RA 9003), on the other hand, establishes a comprehensive framework for managing solid waste in the Philippines. The law provides guidelines for controlling waste generation, storage, collection, transport, processing, and disposal. In addition, the law mandates waste segregation at the source, waste reduction targets for local government units (LGUs), and the establishment of Materials Recovery Facilities (MRFs) in each barangay. The MRFs act as collection and sorting centers for municipal solid waste prior to its disposal in landfills (Cuenco-Inocencio, n.d). The law also prohibits the use of non-environmentally acceptable packaging and illegal waste disposal sites, which directs waste disposal to controlled dumps and sanitary landfills. Additionally, it promotes recycling programs, composting, and eco-labeling to encourage sustainable waste management practices (Aquino et.al., 2022).

Furthermore, the local governments play a crucial role in implementing the national strategies effectively. In 2021, the City Environment and Natural Resources Office (CENRO) of Malaybalay City implemented several key initiatives to enhance waste collection. One of the standout programs was the Eco-Savers Program. This program involved 13 elementary schools in the city where recyclable materials were collected from students, parents, and school operations. The program was able to collect 9,439.77 kilograms of recyclable materials in 2021, with paper making up 86.14% of the total. Additionally, the City Linis Program employed 2,700 residents in 2021 to maintain cleanliness in the city. Beneficiaries were involved in various activities, including beautification, waste management, and addressing litter issues. Regular meetings were held between the City Solid Waste Management Board and the City Clean and Green Committee to discuss important regulations and improvements to waste management practices (City Environment and Natural Resources Office, n.d.). In addition, the city enhanced its waste collection capabilities by acquiring four new garbage trucks valued at Php 11.96 million. These trucks are crucial for improving waste collection efficiency (The City Government of Malaybalay, 2024).

To better understand the scale and efficiency of waste collection in Malaybalay City, figure 2-1 below illustrates the distribution of waste collected from the 46 barangays, represented in percentages. This data is based on the 2023 barangay Materials Recovery Facility (MRF) inventory compiled by the Malaybalay CENRO. The figure highlights the top 5 barangays with the highest waste collection, while the remaining 41 barangays are aggregated into a single percentage. However, the data highlights the disparities in waste collection across the city.

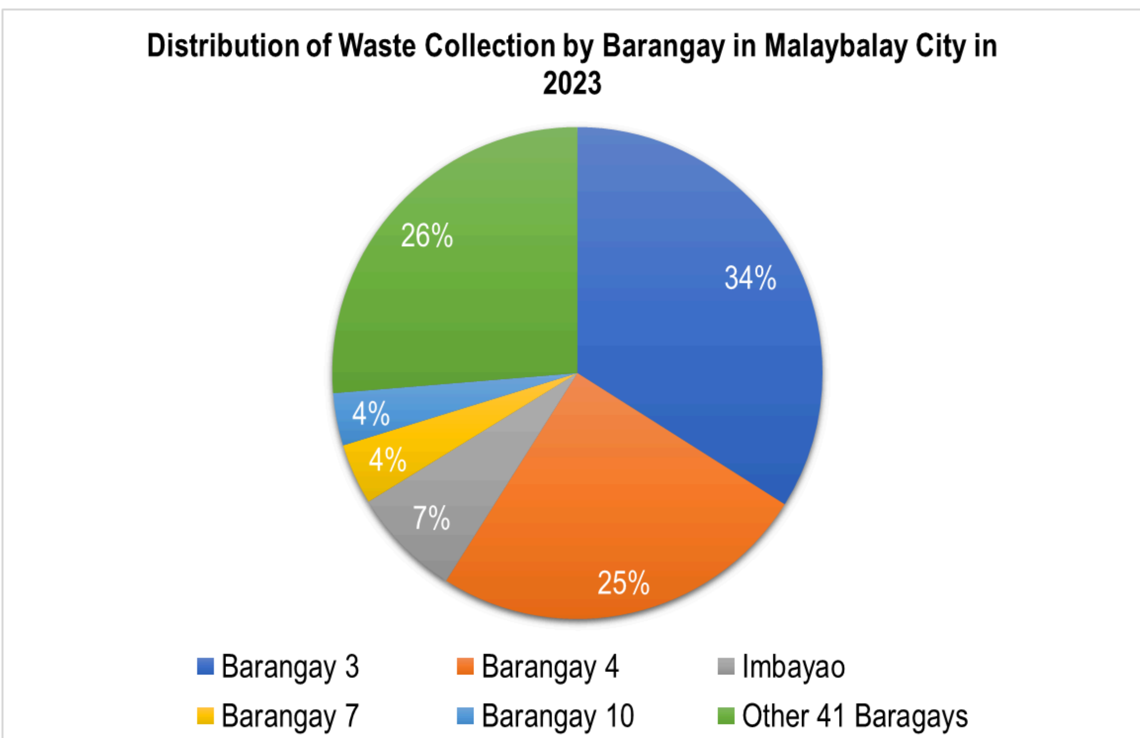

Figure 2-1. Distribution of Waste Collection by Barangay in Malaybalay City in 2023

According to figure 2-1, barangay 3 accounts for 34% of the total waste collected, followed by barangay 4 at 25% and Imbayao at 7%. In contrast, both barangay 7 and barangay 10 contribute only 4%. However, the combined waste collected from the other 41 barangays amounts to just 26%, which is still less than the waste collected in Barangay 3 alone. The significant disparities in waste collection among barangays reveal that some areas are overwhelmed with waste, whereas others are experiencing significantly lower levels of waste.

Effective waste collection strategies are essential to maintaining sustainable municipal solid waste management systems across international, national, and local contexts. International policies, such as Extended Producer Responsibility (EPR), play a significant role in promoting proper waste disposal practices worldwide. Moreover, national strategies, such as the Ecological Solid Waste Management Act, provide a comprehensive framework for managing waste, encouraging reuse and recycling, and reducing landfill dependency. Additionally, the Malaybalay City government further enhances these strategies through community-driven programs. However, the global production of solid waste has reached alarming levels along with the rise of urbanization, rapid industrial growth, and increasing consumption. It is particularly severe in developing countries due to inadequate waste collection services, poor separation of waste types, and heavy reliance on unmanaged landfills (Lama, 2024). Moreover, the barangay Material Recovery Facility (MRF) inventory from CENRO indicates that certain areas of Malaybalay City are experiencing high levels of waste collection (City Environment and Natural Resources Office, 2023). The data highlights variations in waste volumes across barangays, with some areas generating substantial waste, suggesting a need for improved waste collection strategies to manage these higher demands effectively.

2.1.3 The Role of IoT Technologies and Object Detection Algorithms in Waste Collection

As cities grow and waste generation increases, traditional methods of waste collection are becoming less effective in managing the rising demands. However, the integration of advanced technologies, such as object detection algorithms and Internet of Things (IoT) technology, can significantly enhance the effectiveness of waste collection.

The Internet of Things (IoT) refers to a system of interconnected devices that communicate and share data with other IoT systems and the cloud. These devices are often equipped with technologies like sensors and software (Yasar & Gillis, 2024). Moreover, it is an innovative solution to handling and collecting waste. It offers insights into waste generation patterns and behaviors, which enables municipalities, cities, and waste collectors to enhance their waste management operations (Nordsense, 2023). Furthermore, Jasim et al. (2021) highlighted that IoT applications facilitate real-time monitoring and automated collection, which improves the overall waste collection and management process. Venu (2023) presents an example of this technology with a microcontroller system. The microcontroller uses ultrasonic sensors to provide live updates on garbage levels to a mobile web browser through Wi-Fi. This innovation has the potential to reduce garbage truck routes by 30%, which in turn can lower emissions and contribute to cleaner environments. However, the use of IoT applications and ultrasonic sensors is not without limitations. For instance, ultrasonic sensors can be affected by environmental factors such as temperature and humidity, which may lead to inaccuracies in distance measurement. Additionally, the reliance on Wi-Fi connectivity poses challenges in areas with poor network coverage, potentially disrupting data transmission.

Furthermore, object detection algorithms can recognize and pinpoint particular objects of interest within an image or video (Bogguettaya et.al., 2022). In waste management, these detection systems can be implemented on various devices, including cameras or drones, to identify and classify different waste types, such as plastics, glass, paper, and organic materials (Rajkumar et.al, 2023). Additionally, there are different object detection algorithms. These include Faster R-CNN, Support Vector Machines (SVMs), Convolutional Neural Network (CNN), and YOLO (You Only Look Once). These algorithms are essential in various applications, particularly in waste management systems. It also improves waste collection through identification and classification of waste types like plastics and organic materials. Moreover, object detection algorithms enable technologies to reward users for recycling, which promotes environmentally friendly behavior (Ghael et al., 2021; Gibovic & Bikfalvi, 2021). However, these systems also face limitations. Advanced systems often require high integration and infrastructure costs. In local contexts, challenges such as limited access to technology and low user engagement can reduce the effectiveness of these applications, especially in areas with limited resources (Yaddanapudi et al., 2023; Michelle et al., 2021). Nevertheless, the analysis of different object detection algorithms allows municipalities to select the most effective solutions based on their advantages. This data-driven decision-making approach significantly improves waste collection strategies.

2.1.4 Analysis of Different Algorithms in Object Detection

In the realm of object detection, various algorithms have been developed to enhance the efficiency and accuracy of identifying items in diverse environments. Among these methodologies, specific tools have gained significance in practical applications, particularly in automated waste management systems. These algorithms are designed to not only detect objects but also to classify and manage waste effectively, contributing to sustainability efforts and the optimization of recycling processes. The evolution of these algorithms has been marked by improvements in speed, accuracy, and adaptability, making them essential in addressing the challenges posed by waste management and environmental conservation.

Table 2-1. Comparison of Object Detection Algorithms for Waste Management

List of Algorithm	System Title	Strengths	Weaknesses	References
Haar Cascade Classifier	Collection of Plastic Bottles by Reverse Vending Machine Using Object Detection Technique	Rapid object detection for real-time applications. Easy to implement, enhancing accessibility for developers. Excels in face detection in controlled environments.	Struggles under varying lighting, impacting accuracy. Limited in recognizing diverse orientations. Requires large, annotated datasets.	Yaddanapudi et al., (2023)
Support Vector Machines (SVMs)	A comprehensive survey on support vector machine classification: Applications, challenges and trends.	Effective for classification and regression. Strong in high-dimensional spaces. Versatile kernel functions for complex data.	High training time with large datasets. Complicates multi-class tasks. Performance relies on parameter tuning.	Cervantes et al., (2020)

Convolutional Neural Network (CNN)	Convolutional Neural Network Based Partial Face Detection	Achieved 96.2% accuracy in face recognition. Automatically extracts features, handling variations well. Scales to larger datasets.	Requires large labeled datasets. Resource-intensive training process. Risk of overfitting on small datasets.	Islam et al., (2022)
Faster R-CNN	Analysis of Object Detection Performance Based on Faster R-CNN	Strong performance via region proposal network (RPN). Allows joint training, streamlining processes. Excels in feature learning.	Effectiveness declines with low-quality data. Resource-intensive for real-time applications. Complex architecture requires expertise.	Li, W. (2021)
PicoDet	Real-time Waste Detection Algorithm Based on Optimized PicoDet	Achieves 97.30% accuracy and 98 FPS. Suitable for low-power systems. Enhances feature extraction with BiFPN.	Performance depends on dataset quality. High training accuracy raises overfitting concerns. Resource requirements may exceed capabilities of constrained devices.	Peng et al., (2022)

List of Algorithm	System Title	Strengths	Weaknesses	References
Mask R-CNN	Object Detection via Gradient-Based Mask R-CNN Using Machine Learning Algorithms	Combines detection with instance segmentation. High accuracy, recall, and precision. Enhances interpretability with GradCAM++.	Computationally intensive, affecting speed. Requires substantial labeled data. Complexity complicates implementation.	Xavier et al., (2022)
RetinaNet	RetinaNet-based Approach for Object Detection and Distance Estimation in an Image	Enables detection and distance estimation. Achieves a low error rate around 5%. Suitable for real-time applications.	High computational demands. Complex architecture needing extensive tuning.	Alhasanat et al., (2021)

Single Shot Multibox Detector (SSD)	Single shot multibox detector object detection based on attention mechanism and feature fusion	Enhances multiscale detection and speed. Achieves 84.67% mAP on PASCAL VOC dataset. Effectively detects challenging targets.	Increased complexity may affect real-time applications. Reliance on specific datasets limits generalizability.	Wang et al., (2023)
EfficientDet	An evaluation of EfficientDet for object detection used for indoor robots' assistance navigation	Lightweight solution for indoor object detection. Achieves 89% precision at 31 FPS for the basic model. Weight pruning reduces network size.	May need more optimization for resource-constrained environments. Pruning can lead to accuracy loss.	Afif et al., (2022)
Detectron2	COVID-19 Detection from Chest X-Ray Images Using Detectron2 and Faster R-CNN	Utilizes Faster R-CNN for rapid COVID-19 diagnosis. Visual bounding boxes enhance localization. Improves diagnostic efficiency.	Requires significant computational resources. Performance depends on dataset quality. May not replace expert interpretation in complex cases.	(Sakib et al., 2024)

List of Algorithm	System Title	Strengths	Weaknesses	References
CenterNet	An Improved Object Detection Algorithm Based on CenterNet	Introduces an attention module for better feature representation. Maintains a fast detection speed of 12 ms per frame. Multi-scale training reduces overfitting.	Dependence on specific dataset augmentations. Improvements could complicate implementation.	Zou et al., (2021)
YOLO (You Only Look Once)	Object detection using YOLO: challenges, architectural successors, datasets and applications.	Exceptional efficiency and speed for real-time detection. High accuracy and fast inference times. Effective in automated waste management and recycling.		(Diwan et al., 2022). Maity et al. (2023) Rotkreuz (2024)

YOLO (YOU ONLY LOOK ONCE) Algorithm-based Automatic Waste Classification System. Enhancing Sustainable Recycling with Automated Identification of Colored Glass Bottles Using YOLO Object Detection. An automated solid waste detection using the optimized YOLO model for riverine management.	Strong performance in identifying multiple object classes with minimal retraining. Improves sorting accuracy through advanced visual pattern recognition. Supports sustainability by enhancing recycling practices and resource management. High accuracy in classifying colored glass bottles with over 80% mAP. Achieves a mean average precision (mAP) of 89% for identifying multiple garbage classes. Performs well under varying conditions like fluctuating illumination and complex backgrounds.	Zailan et al. (2022)

Table 2-1 shows the comparison of object detection algorithms for waste management, providing insights into their relative strengths and weaknesses. This evaluation is essential as it helps identify the most effective tools for enhancing waste management processes. In researching systems related to the proposed solution, the researchers found out that YOLO (You Only Look Once) is frequently regarded as the leading object detection algorithm, particularly with its latest iterations, YOLOv5 and YOLOv8. Known for its speed and efficiency, YOLO excels in real-time applications, performing exceptionally well in diverse scenarios, from autonomous driving to automated waste management (Badgujar et al., 2024). The algorithm balances high detection accuracy with rapid inference times, making it a preferred choice in contexts where quick decision-making is crucial (Maity et al., 2023).

While YOLO stands out, other significant algorithms contribute to object detection, including Faster R-CNN, SSD (Single Shot MultiBox Detector), Mask R-CNN, and RetinaNet. Faster R-CNN excels in complex detection tasks with high accuracy but demands more computational resources, which can limit its use in time-sensitive scenarios (Li, W. 2021). SSD balances speed and accuracy effectively without extensive resource demands, but it may struggle with detecting small objects or those in crowded scenes (Wang et al., 2023). Mask R-CNN gets very accurate results by combining object detection and instance segmentation, but it takes a lot of computing power, which could slow down real-time processing (Xavier et al., 2022). RetinaNet addresses class imbalance and offers effective object detection but also requires significant computational resources (Alhasanat et al., 2021). Among these, YOLO (You Only Look Once) remains the best algorithm, known for its speed and high mean average precision, making it ideal for real-time applications like waste management. While those algorithms are recognized for their accuracy, they typically do not match YOLO's speed in real-time scenarios (Kumar et al., 2020). Ultimately, the choice of the "top" algorithm depends on specific requirements, including speed, accuracy, and the application context.

In summary, selecting an object detection algorithm requires balancing speed and accuracy to meet specific application needs. YOLO stands out for its high mean Average Precision and fast inference times, making it ideal for real-time scenarios like waste management, where prompt and accurate identification of waste is crucial for effective management and recycling efforts.

2.1.5 The Advantage of YOLO on Efficient Recycling Solutions

Among the algorithms mentioned above, various options exist, but the YOLO algorithm offers distinct advantages that make it the best choice for this study. Despite the strengths of each method, YOLO stands out due to its remarkable efficiency, speed, and adaptability in real-time object detection tasks (Badgujar et al., 2024). In 2015, the real-time object detection system YOLO was introduced, quickly evolving through various iterations, with YOLOv8 released in January 2023. This single-stage detector achieves high detection accuracy and fast inference times, making it widely adopted across many applications (Diwan et al., 2022).

As the field of object detection continues to evolve, You Only Look Once (YOLO) has emerged as an advanced algorithm designed for real-time detection and classification, playing a crucial role in automated waste management systems. Maity (2023) emphasizes the significance of technologies like YOLO in sorting and recycling, transforming waste into valuable resources. Similarly, Rotkreuz (2024) showcases YOLO's effectiveness in automating the identification of colored glass bottles, thereby improving sustainable recycling practices. By enhancing sorting accuracy through complex visual pattern recognition, YOLO supports sustainability efforts aimed at efficient resource management and environmental protection.

The study by Zailan et al. (2022) highlights an enhanced YOLO model for an automated detection system that can identify floating debris, achieving a mean average precision (mAP) of 89% across five waste types, including plastic bottles and aluminum cans. This establishes a solid foundation for effective waste management through precise identification. Furthermore, YOLO's ability to generalize across various object classes without extensive retraining enhances its practicality in diverse scenarios. Overall, the combination of speed and accuracy positions YOLO as the optimal algorithm for the project at hand, ensuring effective and efficient waste management solutions.

The literature reviewed the pressing issues surrounding waste generation and collection. The escalating crisis of waste generation poses significant environmental and health risks on global, national, and local levels. To address these challenges, effective waste collection strategies are essential. This includes implementing initiatives like Extended Producer Responsibility and regulatory frameworks such as Ecological Solid Waste Management Act. Local government programs, such as the Eco-Savers Program, show the effort of the local government to tackle waste issues. However, the high levels of waste collection in specific areas in Malaybalay City highlight the need for improved waste collection strategies to effectively manage these higher demands. Innovative technologies, such as IoT and object detection algorithms, offer promising solutions to improve waste collection efficiency. By utilizing these technologies, municipalities can enhance their sorting and collection processes.

2.2 Related System

This section presents a general overview of existing systems that address waste collection using technologies like IoT, machine learning, and incentivization models. Both commercial and research-based systems are explored to show how innovations are transforming waste collection practices globally and locally.

2.2.1 Worldwide and Local Approaches on Waste Collection Systems

Innovative systems are being developed internationally to advance sustainable waste management practices. For example, the study by Yaddanapudi et al. (2023) explores a reverse vending machine designed for collecting plastic bottles. This system utilizes object detection techniques and machine learning algorithms, specifically OpenCV and a Haar Cascade classifier, to accurately identify and classify bottles, aligning with the current study's aim of creating a smart waste management system utilizing IoT technology. Additionally, Gibovic and Bikfalvi (2021) introduce a virtual reward token, RECICLOS, aimed at motivating families to recycle. By incorporating gamification elements, this initiative fosters community involvement in plastic waste management and complements the proposed system's goal of encouraging recycling efforts (Davis & Kim, 2023). The strength of this study effectively combines technological innovation with strategic user engagement methods, positioning itself as a forward-thinking approach to tackling plastic waste management challenges.

The “Intelligent Waste Management System Using Deep Learning with IoT” addresses these challenges by integrating deep learning and IoT technologies. It employs a convolutional neural network (CNN) for effective waste classification and proposes smart trash bins with sensors for real-time monitoring, achieving a classification accuracy of 95.31% and a system usability score (SUS) of 86%, highlighting its effectiveness and user acceptance (Rahman et al., 2022).

The research into Kadus (2020), "Smart Waste Management System using IoT technology" transforms traditional waste collection by integrating smart bins with fill-level sensors, GPS-tracked vehicles, and a central management server. This system allows real-time monitoring of waste levels, dynamic route optimization, and predictive analytics for waste generation. Key features include automated alerts for full bins, data visualization, and user interfaces for collectors and administrators. The strength includes enhanced operational efficiency, cost reduction, lower environmental impact, improved urban hygiene, and data-driven decision-making. Advanced algorithms optimize routing based on actual needs, reducing costs and improving service delivery (Nguyen & Tran, 2023). This IoT-based approach significantly advances urban waste management, promoting sustainability and smarter resource allocation.

The study titled "IoT Based Reverse Vending Machine to Identify Aluminium Material and Allocate Point Reward" by Rana et al. (2022) explores the integration of IoT technology in reverse vending machines (RVMs) to enhance recycling processes, specifically focusing on aluminum materials. This research presents a prototype of an IoT-based RVM that identifies and processes recyclable aluminum cans while providing users with point rewards. The machine employs a combination of sensors, including inductive and capacitive proximity sensors, to detect the type of material being deposited. The data collected is processed by an Arduino Mega microcontroller and transmitted via Wi-Fi to a cloud platform, enabling real-time monitoring and management of the recycling process. One of the primary strengths of this study is its innovative approach to integrating IoT technology into the recycling process, which can significantly enhance operational efficiency and user experience. The ability to provide instant rewards encourages participation in recycling initiatives, potentially increasing the volume of materials processed.

In the Philippines, innovative systems like the "Aluminum Can to WiFi Trading System" (Panganiban, 2020) are enhancing recyclable waste management by facilitating the exchange of aluminum cans and plastic bottles for WiFi access. This system utilizes advanced sensors for efficient sorting and monitoring, The architecture includes a microcontroller-based unit that detects materials and connects to a cloud-based server for real-time monitoring (Michelle et al., 2021). The strength of this study effectively combines innovative technology with practical incentives, fostering a collaborative approach to waste management that could significantly impact recycling behaviors in communities.

Building On innovative recycling solutions, the "BOTE-WIFI: WiFi Access Through Recycling Plastic Bottles" initiative allows users to access free internet by recycling bottles at IoT-equipped stations that validate deposits with smart recognition systems (Dualan et al., 2019). This system uses cloud computing for secure user data management and recycling trend analysis, promoting sustainable practices, (Martinez et al., 2022). The strengths of this study highlight its innovative approach to integrating technology with environmental sustainability. Similarly, the "Development of a System for Converting Recyclable Materials into Virtual Points" (Cosio et al., 2023) transforms materials like PET bottles and paper into virtual rewards (RAMCoins), employing various recognition methods.

The study of Sarmiento andGito(2024), titled "Wireless Internet-Connected Incentive System for Collecting Plastic Bottles," presents an innovative solution to plastic waste in the Philippines. Using advanced image processing and machine learning, the system accurately identifies and sorts plastic bottles, automating the process with microcontrollers and motors to encourage user participation. Its success hinges on user engagement; if rewards lack appeal, participation may drop. By employing IoT technology, the system tracks the weight of deposited bottles, converting it into virtual currency accessible via a mobile app, redeemable for various benefits, thereby promoting sustainability and enhancing recycling efforts. The research underscores the significance of real-time data tracking and IoT integration in waste management efficiency (Rahman et al., 2020).

The research on "Smart Waste Management System Using IoT Technology" (Kadus , 2020) examines how IoT improves waste management through smart sensors that monitor bin fill levels, enabling optimized collection routes and better vehicle maintenance .Offers significant advantages in terms of efficiency and sustainability, (Kamsiah et al., 2023). Similarly, the "Collection of Plastic Bottles by Reverse Vending Machine" utilizes machine learning for bottle detection and rewards customers with electronic coupons.

The "Incentives for Plastic Recycling" initiative uses the virtual reward token RECICLOS to enhance user engagement, allowing rewards to be redeemed in raffles via a web app for material registration and feedback. By providing virtual incentives (RECICLOS) and lotteries as the rewards to encourage participation in recycling. Another study focuses on converting recyclables into virtual rewards. Collectively, these projects showcase innovative uses of machine learning, IoT, and incentivization in recycling.

While the technological innovations discussed above have enhanced the functionality and efficiency of waste collection systems, the success of such systems also heavily depends on how users interact with them. A well-designed user interface (UI) and a positive user experience (UX) are critical factors in ensuring that users can easily engage with the system, thereby increasing participation and system effectiveness.

2.2.2 User Interfaces (UI) and User Experience (UX) on Existing Waste Collection Systems

This section explores the UI and UX of various waste collection systems, highlighting how different approaches enhance user interactions and promote recycling. A crucial aspect of successful waste collection systems is the design of the user interface (UI) and user experience (UX), as these elements directly impact user engagement and satisfaction. The previously mentioned systems utilize diverse UI/UX strategies to streamline interactions, facilitating greater participation in recycling practices.

The study titled "Wireless Internet-Connected Incentive System for Collecting Plastic Bottles" by Sarmiento andGito(2024) focuses on the design and implementation of a user interface (UI) and user experience (UX) that encourages active engagement in the collection and segregation of plastic bottles. The system integrates an intuitive user interface with a wireless internet-connected incentive mechanism and a plastic bottle segregation system. This approach effectively manages plastic bottle accumulation while fostering active participation. The UI is designed to be user-friendly, enabling easy access and participation through an incentive-based reward system, which is further enhanced by providing free Wi-Fi connectivity to students. The overall UX is crafted to be engaging and motivating, promoting sustainable practices through technology-driven solutions

The study of Kadus et al. (2020) titled "Smart Waste Management System using IoT" focuses on integrating IoT technologies into waste management to enhance cleanliness and hygiene in urban environments. The system, known as "Smart Netbin," incorporates both hardware and software components to create a more efficient and incentivized waste management process. The primary innovation involves a modified dustbin equipped with sensors, a shredder, and a Wi-Fi router that offers temporary internet access as a reward for users who dispose of their waste properly. This approach not only simplifies the design and reduces costs compared to existing systems but also encourages public participation in maintaining cleanliness by offering tangible benefits, thus addressing issues of improper waste disposal and its adverse effects on public health and the environment

The “Intelligent waste management system using deep learning with IoT" by Rahman et al. (2020), the user interface (UI) and user experience (UX) are integral aspects of the developed system, which includes an IoT-based smart trash box and an Android application for real-time waste monitoring. The system usability was assessed using the System Usability Scale (SUS), which resulted in a score of 86%, indicating high user satisfaction. This score reflects the effectiveness and ease of use of the UI/UX, as 42% of participants strongly endorsed the system, 44% endorsed it, while only a small fraction remained neutral or gave a negative response 1. The Android application allows users to monitor the waste level and weight in the trash box, showcasing practical and user-friendly UI/UX design elements that enable efficient interaction and real-time data access.

In the study by Gibovic and Bikfalvi (2021) titled "Incentives for Plastic Recycling: How to Engage Citizens in Active Collection. Empirical Evidence from Spain," the UI and UX were critical elements of the RECICLOS project. The UI was modern and engaging, leveraging gamification features such as lotteries and raffles to involve users in recycling. Users registered their plastic recycling efforts through a web app by scanning items, earning virtual tokens redeemable for rewards. Although there were initial issues like slow loading times, the app effectively engaged users, with 1,053 families (10% of the target population) participating in the pilot.

The UX was significantly enhanced by the use of gamified incentives, which motivated recycling behavior more effectively than traditional rewards like discounts. The interactive and rewarding nature of the process improved the overall experience, making it both engaging and motivating. This study demonstrated the power of digital platforms in driving citizen participation in recycling through a combination of behavioral insights and technology.

Furthermore, the research study by Dualan et al. (2019) titled "BOTE-WIFI: WIFI Access Through Recycling Plastic Bottles" prioritizes the UI and UX aspects by focusing on product usability and functionality. The UI is designed to be simple and user-friendly, ensuring users can easily navigate the system with clear, helpful instructions, which were found to be crucial for user understanding. On the UX side, user satisfaction is emphasized, with positive feedback when the system works without complications. Key factors for UX success included stable internet speeds, easy connectivity, and the system's overall simplicity, which enhanced the user experience.

Lastly, the study by Rana et al. (2022) on the "IoT Based Reverse Vending Machine to Identify Aluminium Material and Allocate Point Reward" focuses on encouraging recycling behavior using an IoT-based Reverse Vending Machine (RVM). The system's UI and UX are designed for seamless user interaction, enabling easy sign-up via phone numbers and tracking recycling activities like the number of aluminum cans recycled and points earned. The user-friendly design, supported by the MQTT protocol, simplifies reward redemption. The cashless rewards system further improves efficiency and security, promoting higher user engagement in recycling activities.

2.2.3 Algorithms in Waste Collection Systems

Waste collection systems increasingly rely on algorithms to optimize their operations and improve efficiency. Many of these systems incorporate IoT technology alongside advanced algorithms to enhance performance. For instance, systems like those developed by Sarmiento andGito(2024), Kadus (2020), Rahman et al. (2022), and Yaddanapudi et al. (2023) combine IoT technology with algorithms to improve efficiency. These systems use various algorithms to optimize waste management. In contrast, some systems focus solely on the use of algorithms without IoT integration. For instance, the study by Gibovic and Bikfalvi (2021) employs RECICLOS algorithms and blockchain technology without involving IoT. Whether the system incorporates IoT or not, these systems highlight the essential role algorithms play in enhancing the efficiency of waste collection.

For instance, the study of Sarmiento andGito(2024), titled "Wireless Internet-Connected Incentive System for Collecting Plastic Bottles”, utilizes clustering algorithms such as K-means clustering or DBSCAN. It is used to segment users based on their recycling habits. This segmentation allows for tailored reward distribution, which improves engagement through personalized incentives. The system further incorporates association rule learning algorithms, such as Apriori and FP-Growth, to analyze user interaction patterns. This ensures that users are rewarded appropriately for their contributions, making the point system fair and improving the overall user experience.

Furthermore, the system of Kadus (2020), "Smart Waste Management System", incorporates predictive algorithms that analyze collected data to forecast waste generation patterns. These algorithms optimize collection routes and schedules, improving overall operational efficiency and minimizing cost.

The research conducted by Rahman et al. (2020) in the study titled “Intelligent Waste Management System Using Deep Learning with IoT” employs a convolutional neural network (CNN) for waste classification. It specifically employs a pre-trained ResNet-34 model. This model is used to categorize waste into digestible and indigestible types, achieving an accuracy of 95.3125%. The CNN processes images of waste to classify it into six categories, namely cardboard, glass, metal, paper, plastic, and trash.

The study of Yaddanapudi et al., (2023), the “Collection of plastic bottles by reverse vending machine using object detection technique” used OpenCV and Haar Cascade classifiers. These algorithms are employed to classify objects as a cost-effective alternative to using sensors in the machine. Haar Cascade is a reliable object detection algorithm that can recognize items in images, regardless of their size or position. According to Shetty et al. (2021), Haar feature-based cascade classifiers use a machine learning technique that involves a cascade operation to identify objects. This method is effective for recognizing faces and expressions by training on both positive and negative images.

Additionally, the study by Gibovic and Bikfalvi (2021), titled “Incentives for Plastic Recycling Initiative,” used RECICLOS algorithms. The RECICLOS project incorporated various algorithms and technological frameworks to enhance its plastic recycling efforts. A significant component of this project was the implementation of blockchain technology, specifically the Alastria testnet, which is based on Ethereum and utilizes a Proof of Authority consensus mechanism. This blockchain framework provided transparency and trust within the system, especially regarding the management of lotteries and the selection of winners.

2.2.4 IoT Technology in Waste Collection Systems

The integration of IoT technology has revolutionized waste collection systems. Several systems, such as those developed by Sarmiento andGito(2024), Kadus (2020), Rahman et al. (2022), and Yaddanapudi et al. (2023), leverage both IoT technology and advanced algorithms to optimize waste management processes. Other systems, on the other hand, focus purely on IoT technology without incorporating algorithms such as those developed by Cosio et.al (2023), Dualan et.al (2019), and Rana et al. (2022). While these systems may not utilize algorithms, their reliance on IoT technology plays a crucial role in real-time monitoring, automating processes, and encouraging recycling through rewards.

Furthermore, the study of Sarmiento andGito(2024), titled "Wireless Internet-Connected Incentive System for Collecting Plastic Bottles," presents an innovative solution to plastic waste in the Philippines. This system uses advanced image processing and machine learning to accurately identify and sort plastic bottles. It automates the sorting process with microcontrollers and motors, which helps encourage user participation. However, its success hinges on user engagement. If rewards lack appeal, participation may drop. To enhance this engagement, the system employs IoT technology to track the weight of deposited bottles. This data is then converted into virtual currency accessible via a mobile app, which can be redeemed for various benefits. By providing tangible rewards, the system promotes sustainability and encourages recycling efforts. The research underscores the significance of real-time data tracking and IoT integration in improving waste management efficiency (Rahman et al., 2020).

Additionally, the study by Kadus (2020), titled "Smart Waste Management System Using IoT Technology," utilizes several key IoT technologies to automate and incentivize waste disposal. The system features a load sensor that measures the weight of the trash, an infrared (IR) sensor that detects when trash is deposited, and a Wi-Fi module that provides internet access as a reward for proper waste disposal. The system employs a microcontroller, specifically an Arduino, to process data from these sensors and control the Wi-Fi module. The load sensor plays a crucial role by determining when the trash has reached a specific weight threshold. When this threshold is met, the system triggers the display of a Wi-Fi password on an LCD screen, allowing users to access free internet for a limited time.

The study “Intelligent Waste Management System” by Rahman et al. (2022) utilizes the Internet of Things (IoT) to enhance real-time monitoring and control of waste management processes. This system incorporates a microcontroller, specifically the ESP8266, to connect various sensors such as ultrasonic and load measurement sensors. These sensors are used to measure the waste levels and weight within a smart trash box. The data collected by the sensors is transmitted via Bluetooth for short-range communication to an Android application and also sent to a cloud server for real-time remote monitoring. This setup allows users to monitor waste levels and receive notifications when the trash bin needs attention. The integration of IoT into this system facilitates the efficient management of waste by providing timely data and enabling automated responses to waste bin conditions

The study of Yaddanapudi et al., (2023) “Collection of plastic bottles by reverse vending machine using object detection technique” utilizes Raspberry Pi4 of 2 GB to detect the plastic bottles. This offers improved processor speed, multimedia performance, and extensive peripheral support (Ghael et al., 2021).

In the study by Cosio et al. (2023), titled "Converting Recyclable Materials into Virtual Points," an initiative uses IoT-enabled devices to track recycling activities. These devices connect to cloud-based servers, allowing for real-time monitoring and reward distribution. The system encourages user participation by assigning virtual points based on recycling behavior, which can later be redeemed for incentives.

In the "BOTE-WIFI" project by Dualan et al. (2019), the system primarily uses Internet of Things (IoT) technology with a Raspberry Pi 3 Model B+ as its core component. This device serves as a compact and versatile computer that manages the operations of the Bote-WiFi system, including functioning as a Wi-Fi hotspot. It is programmed with a Raspbian image, using Python and Java scripts to control internet access and facilitate user interaction through a captive portal. Additionally, the system incorporates hardware components such as infrared sensors, which detect the insertion of plastic bottles to activate internet access, and a Wi-Fi modem that connects to the Raspberry Pi to provide network services.

Furthermore, the study of Rana et al. (2022) "IoT-Based Reverse Vending Machine to Identify Aluminium Material and Allocate Point Reward" The system utilizes a structured architectural approach consisting of three primary layers: sensor, communication, and application. The sensor layer incorporates an Inductive Proximity Sensor (IPS) to detect aluminum cans by generating magnetic fields when metallic objects enter its sensing area, an Ultrasonic Sensor (HC SR04) to monitor the fill level of the container through sound wave detection, and a Global Positioning System (GPS) module to track the geographical location of the RVM 1 2. The communication layer utilizes WiFi technology, specifically the Esp8266 module, to transmit data wirelessly to the cloud, facilitating data exchange between the sensors and cloud servers 3. The application layer employs the MQTT protocol, a lightweight publish-subscribe protocol over TCP/IP, to manage machine-to-machine (M2M) communication and provide a user-friendly interface for redeeming reward points 4. These components work together to promote recycling by rewarding users for depositing aluminum cans, while also assisting in data collection for waste management analysis.

2.2.5 Limitations of the Existing Collection Systems

This section examines the limitations of current waste collection systems, highlighting the challenges that hinder their effectiveness and user engagement. Despite advancements in technology, usability remains a significant concern, particularly for non-expert users who may find complex systems difficult to navigate. Furthermore, local collection systems that depend on incentives often struggle to maintain user engagement, as noted by Kadus (2020) and Rahman et.al (2020).

Scalability is another critical issue, as many global systems are tailored for urban settings with the necessary infrastructure to support large-scale deployments. In contrast, local systems frequently encounter obstacles when attempting to scale up due to limited resources (Michelle et al., 2021; Dualan et al., 2019). Additionally, cost presents a prevalent barrier, with high initial investments required for IoT technologies and sensors impacting both global and local systems. Local initiatives, in particular, often find it challenging to secure funding for ongoing maintenance and upgrades (Yaddanapudi et al., 2023; Gibovic & Bikfalvi, 2021).

Accessibility issues further complicate the effectiveness of local systems that aim to enhance access through incentives, such as WiFi. Areas with unreliable internet connectivity face additional challenges (Sarmiento & Espinosa, 2024; Kamsiah et al., 2023). Finally, the study by Muhammad Ehsan Rana et al. (2022) identifies weaknesses related to technical challenges, including sensor accuracy and data transmission reliability, which could adversely affect the performance of these systems in real-world scenarios. The reliance on technology may also alienate users who are less tech-savvy or lack access to smartphones for reward tracking, thereby limiting the overall success of the collection systems.

2.2.6 Comparative Analysis International and Localized Waste Collection Approaches

International and localized waste collection approaches share similarities in their use of technology and incentivization models, but differ in scale and specific implementations. International approaches tend to utilize more advanced technologies such as IoT, deep learning, and machine learning on a larger scale. These systems often implement smart bins with fill-level sensors and GPS tracking, and employ sophisticated algorithms like convolutional neural networks (CNN) for waste classification. In contrast, localized approaches, particularly in countries like the Philippines, integrate IoT and machine learning but often on a smaller scale. They tend to focus on specific waste types, such as plastic bottles or aluminum cans, and utilize simpler technologies like IR sensors and microcontrollers.

In terms of incentivization, both international and localized approaches recognize the importance of motivating user participation. International systems often implement virtual reward tokens, such as RECICLOS, and incorporate gamification elements to engage users. Localized systems, especially in the Philippines, have developed innovative incentive models that cater to local needs and preferences. For example, some systems offer WiFi access in exchange for recycling plastic bottles, addressing both waste management and internet accessibility issues simultaneously.

The scale and scope of implementation differ significantly between international and localized approaches. International systems are often designed for widespread urban deployment, leveraging existing infrastructure and resources. They focus on optimizing large-scale waste management operations, including route planning for collection vehicles and predictive analytics for waste generation. Localized approaches, while smaller in scale, often target specific community needs and are designed to be more adaptable to local conditions and limitations.

Both approaches face challenges in terms of user engagement, system maintenance, and scalability. International systems may struggle with user adoption due to their complexity, while localized systems often grapple with limited resources for expansion and long-term sustainability. However, both approaches demonstrate the potential for technology to significantly improve waste management practices and promote recycling behaviors among users.

Table 2-2. Comparative Study of WiFi from Waste: Converting Recyclable Materials into Internet

Title	Waste Segregation	Paper Scaling	Account Based	Internet Access Rewards	Error Handling type of waste	Authors of the study
Aluminum Can to WiFi Trading System	✓			✓	✓	Michelle et al., (2021)
Wireless Internet-Connecte d Incentive System for Collecting Plastic Bottles	✓	✓	✓		✓	Gito & Sarmiento,(2024)
IoT Based Reverse Vending Machine to Identify AluminiumMaterial and Allocate Point Reward					✓	Rana et al,. (2022)
BOTE-WIFI: WiFi Access Through Recycling Plastic Bottles				✓	✓	Dualan et al.. (2019)
Smart Waste Management System Using IoT Technology					✓	Kadus, (2020).
Intelligent waste management system using deep learning with IoT	✓				✓	Rahman et al., (2020).
Incentives for Plastic Recycling" initiative uses the virtual reward token	✓		✓		✓	Gibovic & Bikfalvi, (2021)
WiFi from Waste: Converting Recyclable	✓	✓	✓	✓	✓	

Materials into
Internet Access

Table 2-2 shows the comparative study of various innovative systems that aim to integrate waste management, recycling, and digital incentives, particularly internet access. The table is titled "Comparative Study of WiFi from Waste: Converting Recyclable Materials into Internet Access to the existing systems features," which encapsulates its primary focus.

2.3 Concept of the Study

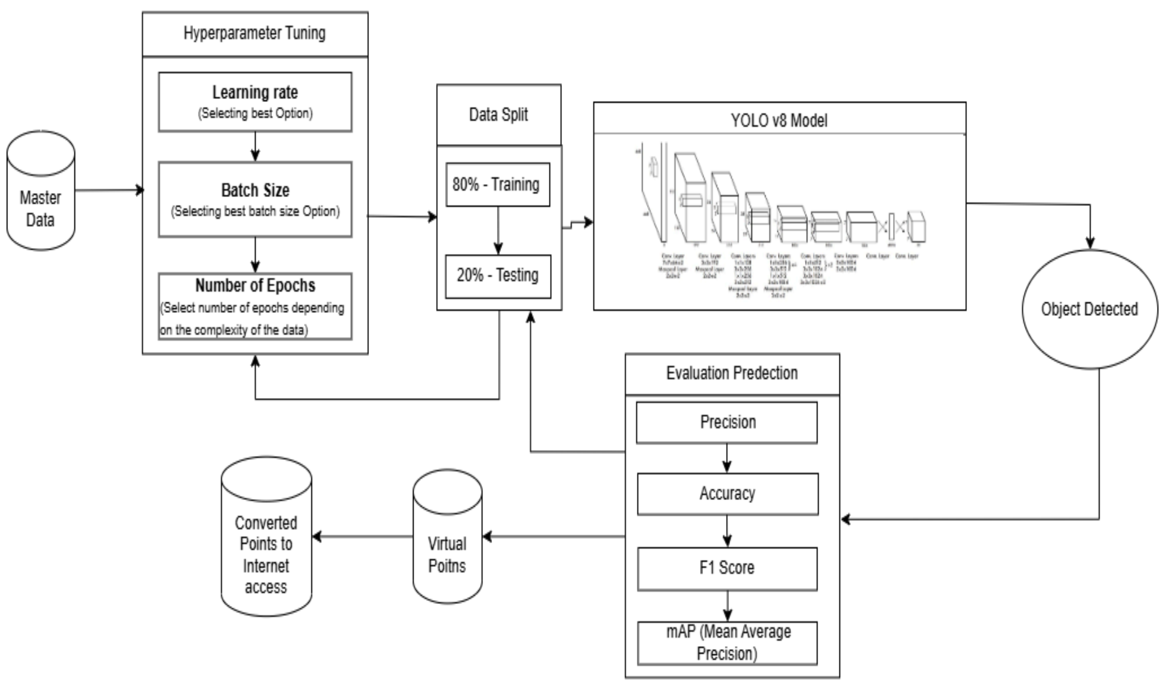

Figure 2-2. Conceptual Framework of WiFi from Waste

Figure 2-2 shows the conceptual framework of WiFi from Waste. The system begins with the input stage, where users submit recyclable materials, such as paper, plastic bottles, and cans, into the system. The materials are processed by a recognition module that uses YOLO (You Only Look Once), a real-time object detection algorithm. This module plays a crucial role in identifying and classifying the materials based on their type and preparing them for the next steps.

Once the materials are recognized, they proceed to the processing stage. Non-paper materials, such as plastic and cans, are placed directly into their respective bins without weighing. Paper materials, however, are weighed by the system. Points are then allocated based on the materials accepted. The point allocation follows a predefined system that values each type of recyclable material differently. When the points meet a certain threshold, the user can exchange them for rewards, specifically internet access. This incentivizes users to recycle more by offering tangible benefits in the form of connectivity, making it an effective tool in both waste management and addressing digital divide issues.

Additionally, system hardware consists of OpenCV and YOLO modules with real-time image detection in order to detect what type of recyclable material it is. The paper will be scaled based on weight, and weight will be computed from the HX711 amplifier. The points will depend on the value of recyclable material, then the points will be allocated to the user's account, and when the points reach the minimum requirement, points can be used to have an internet connection.

In summary, this context has explored various existing systems in the realm of waste collection, highlighting both global innovations and local adaptations. Key findings indicate that while global systems have successfully integrated advanced technologies such as machine learning, IoT, and blockchain to enhance operational efficiency and scalability, they also face significant challenges related to usability, cost, and infrastructure integration. Conversely, local systems have demonstrated the effectiveness of practical incentives in promoting recycling behaviors; however, they often struggle with resource limitations and user engagement. Identifying these gaps provides a foundation for the current study, which aims to develop a system that combines the strengths of both global and local approaches to enhance sustainability in waste management.

The comprehensive review of existing waste collection systems reveals a dynamic landscape of technological innovation and social engagement in addressing global waste management challenges. Both global and local systems increasingly leverage advanced technologies such as IoT, machine learning, and blockchain to optimize waste collection processes, enhance operational efficiency, and promote user engagement. Many systems, particularly at the local level, have adopted incentive-based approaches to encourage recycling behaviors, ranging from virtual reward tokens to practical benefits like WiFi access. The success of these systems heavily relies on user-friendly interfaces and positive user experiences, with systems prioritizing intuitive design and seamless interaction achieving higher user engagement and participation rates. Various algorithms, including clustering, association rule learning, and image recognition techniques like YOLO and Haar Cascade, play crucial roles in optimizing system performance and accuracy.

However, challenges persist. While global systems often benefit from more extensive resources and infrastructure, they face challenges in scalability and high implementation costs. Local systems, although more adaptable, struggle with resource limitations and maintaining long-term user engagement. Some local initiatives aimed at enhancing access through incentives face challenges in areas with unreliable internet connectivity, highlighting the need for context-specific solutions.

These findings underscore the importance of developing a waste collection system that balances technological sophistication with practical, user-centric design. The current study, "WiFi from Waste: Converting Recyclable Materials into Internet Access," aims to address these challenges by integrating advanced recognition technologies (YOLO, OpenCV) for accurate material identification, implementing a points-based reward system that offers internet access as an incentive, focusing on a user-friendly interface to enhance engagement and ease of use, and addressing local needs while incorporating lessons from global systems. By combining the strengths of both global and local approaches, this study seeks to create a more effective, sustainable, and user-friendly waste management solution. The proposed system has the potential to not only improve recycling rates but also contribute to bridging the digital divide, offering a unique approach to addressing environmental and social challenges simultaneously.

2.4 Definition of Terms

Blockchain Blockchain is a record-keeping technology designed to make it impossible to hack the system or forge the data stored on the blockchain, thereby making it secure and immutable.

Circular Economy Circular economy is a model that aims to minimize waste and promote a sustainable use of natural resources through smarter product design, longer use, and recycling.

Faster R-CNN Faster R-CNN is a state-of-the-art object detection algorithm that uses a region proposal network to identify objects in images. It's efficient for detecting multiple objects in real-time.

Haar Cascade Classifier An approach for machine learning object detection that uses attributes to recognize items in a picture or video.

Internet of Things (IoT) The Internet of Things or IoT is a system of interrelated computing devices that can collect and transfer data over a wireless network without human input.

Machine Learning Machine learning (ML) is a branch of artificial intelligence (AI) and computer science that focuses on using data and algorithms to enable AI to imitate the way that humans learn, gradually improving its accuracy.

Programming Language It is a structured communication method used to provide commands to a computer.

RAMCoins RAMCoin is a decentralized currency that operates on a blockchain network, making it secure and transparent.

RECICLOS An online incentive scheme crafted to motivate sustainable actions, thereby encouraging recycling in households.

Reverse Vending Machine (RVM) Reverse vending machine or RVM is a specialized device designed to automate the process of collecting and recycling waste, most commonly used beverage containers such as plastic bottles, glass bottles, and aluminum cans.

RFID Radio Frequency Identification (RFID) the wireless, non-contact use of radio frequency waves to transfer data and identify objects, animals, or humans.

Smart City Smart City as an urban area that has become more efficient and/or more environmentally friendly and/or more socially inclusive through the use of digital technologies.

Support Vector Machine (SVM) Support Vector Machine (SVM) is a supervised learning algorithm commonly used for classification tasks. It finds the optimal hyperplane that separates different classes in a dataset.

Waste Management Waste management is a streamlined process that involves the disposal, reduction, reuse, and prevention of waste.

You Only Look Once (YOLO) You Only Look Once or YOLO is an algorithm capable of detecting objects at first glance, performing detection and classification simultaneously.

3 METHODOLOGY

3.1 Materials

3.1.1 Software

The system will be developed through the use of several software tools. It will utilize Visual Studio Code, GitHub, MongoDB Atlas, and browsers as indicated in Table 3-1 below.

Table 3-1. Software that will be Utilized for the Development of WiFi from Waste

Software	Definition	Version
Visual Studio Code	Visual studio code is a free, lightweight, and powerful source code editor that's compatible with Windows, macOS, and Linux.. It also has a rich ecosystem of extensions for other programming languages, runtimes, environments, and clouds.	2024 1.95.2
GitHub	GitHub is a platform for online software development. It is employed for software project collaboration, tracking, and storage.	3.15.0
MongoDB Atlas	MongoDB Atlas is a multi-cloud database service developed by the creators of MongoDB. It simplifies the deployment and management of databases.	7.0
Browsers	Browsers are used by web developers for testing, debugging, and cross-platform compatibility checks.	Current Versions

3.1.2 Hardware

In addition, the system will integrate software with hardware. The study will employ several hardware components in order to detect and sort recyclable materials from the users. Table 3-2 below shows the list of hardware needed by the system.

Table 3-2. Hardware to be Used for the Development of WiFi from Waste

Hardware Needs	Definition	Price	Model	Picture
Orange Pi 5 4gb	Orange Pi is a series of single-board computers (SBCs) developed and produced by Shenzhen Xunlong Software Co. Ltd. These boards are primarily designed for educational and development purposes.	₱ 1,300	B+	
Raspberry Pi 3 camera	Raspberry Pi Camera Module 3 is a compact camera from Raspberry Pi. It offers an IMX708 12-megapixel sensor with HDR, and features phase detection autofocus.	₱ 1,386	Module 3	
WiFi Vendo	The service operates through vending machines, known as Piso WiFi vendo machines, which are strategically placed in public spaces. Users can connect to the internet by selecting the Piso WiFi network on their device,	₱ 1,200	N/A	

	navigating to the login page, and inserting coins into the machine.			
HX711	HX711 is a precision 24-bit analog-to-digital converter (ADC) designed for weight scales and industrial control applications to interface directly with a bridge sensor.	₱ 70	N/A	
Micro SD Card 32gb	SD Card is a proprietary, non-volatile, flash memory card format used by the SD Association (SDA) to manage images, videos and any project related files.	₱ 400	Sandisk	
recommended model Power Supply 12V 3A	It is a device that converts electric current from source into a correct voltage, frequency, and format for electrical load.	₱ 250	N/A	
Power Supply 5V 3A	It is a device that converts electric current from source into a correct voltage, frequency, and format for electrical load.	₱ 300	N/A	

16x2 LCD Display I2C	The LCD display includes an I2C adapter board based on PCF8574 I2C chip, it converts I2C serial data to parallel data for the LCD display, thus, significantly reducing the number of I/O pins used on the microcontroller to send data to the LCD.	₱ 150	N/A	
DC Gear Motor 12v	DC Gear Motor 12V 526RPM - SGM37-550 is intended to run at 12V but can be driven with lower voltage up to 6V at the expense of power.	₱ 700	526RPM - SGM37-550	
Micro Servo Motor	Micro servo motor is a small, versatile servo motor that can rotate 360 degrees.	₱ 100	180/360 Degree Servo Motor	
IR Proximity Sensor	IR Proximity Sensor is a multipurpose infrared sensor which can be used for obstacle sensing, color detection, fire detection, line sensing, etc. and also as an encoder sensor. The sensor provides a digital output.	₱ 50	N/A	

Tactile Switch	Switch 12mm Square are commonly used in many consumer electronic devices. Momentary switch is a switch which only remains in its own state as long as they're being actuated (pressed, held, magnetized, etc.).	₱ 30	N/A	
Wires	Jumper wires are 100mm/200mm/300mm long and come in a 'strip' of 40 (4 pieces of each of ten rainbow colors). They have 0.1? male / female header contacts on either end and fit cleanly next to each other on standard-pitch 0.1? (2.54mm) header. The best part is they come in a 40-pin ribbon cable.	₱ 50	N/A	
Lan Cable	A LAN cable, or Ethernet cable, is a physical cable that connects devices to a local area network (LAN). LAN cables usually connect computers, printers, routers, and other network devices.	₱ 200	CAT6 E	

PVC Tubes 200mm	PVC tubes, or polyvinyl chloride tubes, are flexible containers made from a synthetic resin that is molded into different shapes.	₱ 100	N/A	
Plywood	A structural material consisting of sheets of wood glued or cemented together with the grains of adjacent layers arranged at right angles or at a wide angle.	₱ 200	N/A	
Cart Wheel	A simple machine consisting of a circular frame which will be use to support the hardware structure in travelling from one place to another.	₱ 165	N/A	

3.1.3 Data

The development of the system is supported by data sourced from records and findings relevant to recyclable materials. Baseline data were obtained from the 2023 Materials Recovery Facility (MRF) inventory report and the Eco-Savers program data provided by the City Environment and Natural Resources Office (CENRO) of Malaybalay City. Additional information was gathered from Razzman Junk Shop for the pricing of recyclables.

The data collection for the system project encompasses various types of data crucial for system development:

1. Recyclable Material Data: The system primarily processes three types of recyclables namely, plastic bottles, cans, and paper. According to the Eco-savers program, paper accounted for 86.14% of the recyclables collected by the local government in 2021. Moreover, cans and plastic bottles, particularly mineral plastic bottles, accounted for 16% of the total sales in the MRF Inventory of Malaybalay CENRO in 2023. These materials were ranked as the second most profitable recyclables, with paper ranking the third (City Environment and Natural Resources Office, n.d.). Furthermore, the pricing information from Razzman Junk Shop helps define the point-based reward system, where higher-value recyclables, such as cans, are allocated more points compared to paper.
2. Algorithm Training Data: During the development phase, image datasets will be created by capturing photographs of plastic bottles and cans. Additionally, publicly available datasets will be used to supplement the training data. The dataset will be split into 80% for training and 20% for testing. Moreover, the algorithm's performance will be evaluated using metrics such as mean Average Precision (mAP), Intersection Over Union (IoU), precision, and recall. It will also be evaluated through F1-score, confusion matrix, and detection time to ensure reliable classification of recyclables.
3. System Evaluation Data: The system's effectiveness will be evaluated using the standards outlined in ISO/IEC 25010:2023. The survey will focus on quality characteristics that are most relevant to the end user such as usability, functional suitability, and performance efficiency.

In addition to the data collected from the selected barangay, the system will incorporate the use of algorithms for waste classification. This algorithm will process the image data collected to accurately categorize materials. The data will be securely stored in MongoDB Atlas to ensure data privacy and protection.

3.2 Methods

3.2.1 Research Design

This study employs a developmental research design, which will focus on the iterative process of designing, developing, and evaluating the system. The study will involve analyzing quantitative data, such as the weight and type of recyclables collected. The researchers will also evaluate the YOLO algorithm's performance using metrics like mAP, precision, recall, F1-score and Intersection Over Union. In addition, data collection will include assessing the effectiveness of the web application using established standards namely, usability, functional suitability, and performance efficiency. . These aspects will be evaluated through survey questionnaires to ensure the system meets performance expectations and effectively encourages recycling.

3.2.2 You Only Look Once (YOLO) Algorithm

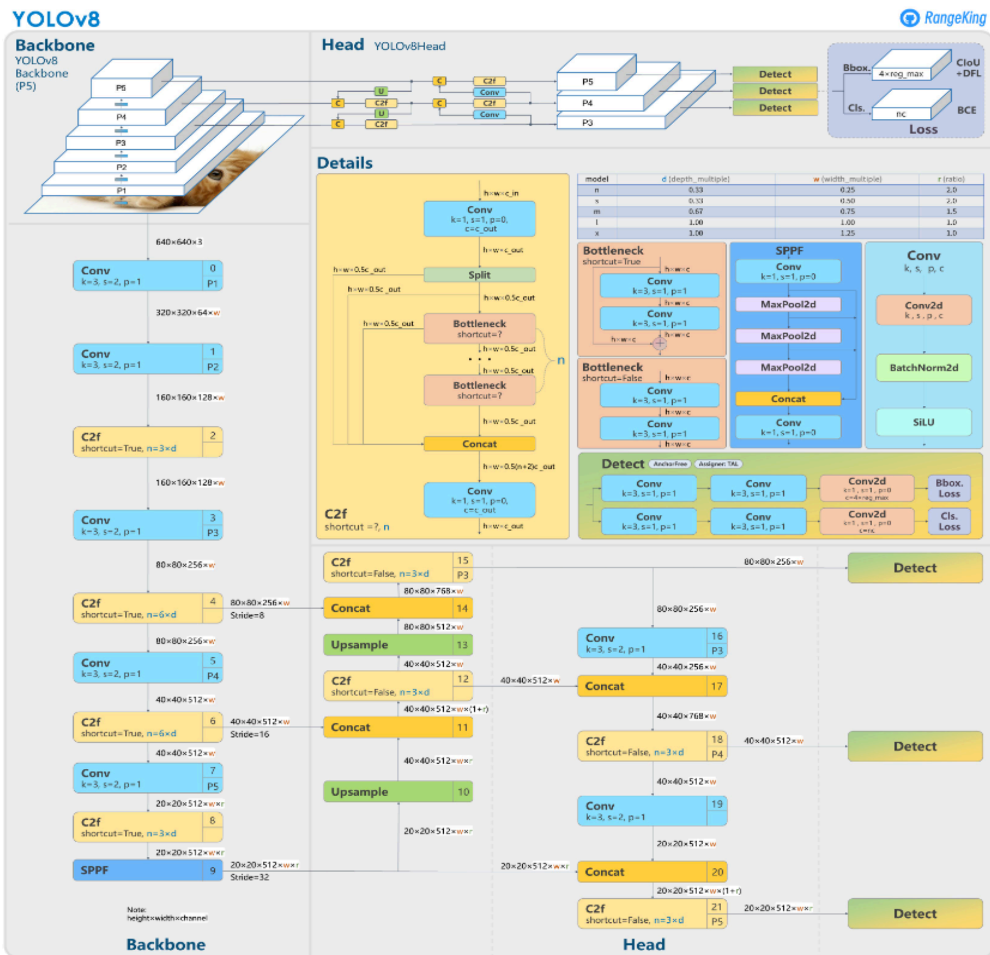

Figure 3-2. YOLOv8 Architecture by a GitHub user RangeKing

The YOLOv8 architecture, illustrated in Figure 3-2, is a framework designed for real-time object detection and classification, which is crucial for applications such as automated recycling systems. The key principle of YOLO (You Only Look Once) lies in its ability to process the entire image in a single pass, which sets it apart from older object detection algorithms that rely on multiple stages. This unified approach allows YOLO to quickly and accurately identify and classify objects, making it ideal for real-time tasks. YOLOv8, as the latest version, builds upon previous iterations to deliver enhanced performance through improvements in speed, accuracy, and flexibility, particularly in challenging environments like waste sorting.

The process of YOLOv8 begins with an input image, which is typically resized to a fixed size (such as 416x416 or 608 x 608 pixels) to ensure uniformity. This image is then divided into a grid, where each grid cell is responsible for detecting objects within its region. Unlike traditional methods that first generate region proposals and then classify them, YOLO predicts bounding boxes, class labels, and confidence scores for all potential objects in the image simultaneously. This eliminates the need for separate steps, which allows YOLO to perform real-time detection.

The next step involves the backbone of YOLOv8, which is based on the CSPDarknet model. This component extracts high-quality features from the input image using convolutional layers. These features are crucial for recognizing patterns, textures, and shapes that represent different objects. The extracted features are then processed by Feature Pyramid Networks (FPNs), which help YOLO detect objects at different scales by capturing contextual information at multiple levels of resolution. This multi-scale feature extraction enables YOLO to detect objects of various sizes, such as small plastic bottles and large aluminum cans, with equal precision.

After feature extraction, the neck layer of YOLOv8, which integrates a Path Aggregation Network (PANet), plays a critical role in refining the extracted features. PANet enables a smooth flow of information between different layers of the network, combining data from lower and higher levels to improve object localization. This process is essential in waste sorting systems, where objects might overlap or be partially visible, ensuring that YOLO can accurately distinguish between materials, even in cluttered environments. PANet’s ability to aggregate information from various levels enhances the model's robustness, ensuring that it can reliably detect objects despite noise or background clutter.

The final stage of YOLOv8 is the head, where the detection results are generated. This includes predicting bounding boxes for objects and classifying them into predefined categories, such as plastic bottles, cans, or paper. YOLOv8 utilizes an anchor-free detection mechanism, which simplifies the detection process by eliminating the need for pre-defined anchor boxes. This innovation reduces the computational complexity while maintaining the model’s accuracy. Additionally, YOLOv8 uses dynamic convolutions and adaptive activation functions to further optimize detection precision without compromising speed. The use of advanced loss functions, such as Complete Intersection over Union (CIoU), improves bounding box regression, ensuring that objects are tightly and accurately framed.

In the context of recycling, YOLOv8’s ability to quickly and accurately detect and classify recyclable materials such as plastic bottles and cans in real-time enhances the efficiency of waste sorting systems. By automating the identification process, YOLO reduces the reliance on human intervention and minimizes errors in sorting, leading to more accurate and efficient recycling operations. Furthermore, YOLOv8's adaptability allows it to be retrained to recognize new types of recyclable materials, ensuring the system remains effective as waste streams evolve. This scalability is crucial for handling the growing complexity of waste materials, making YOLOv8 an invaluable tool for sustainable waste management.

Overall, YOLOv8’s unified, multi-scale approach, along with its ability to process images quickly and accurately, makes it an excellent choice for automated recycling systems. Its ability to integrate various advanced techniques, such as dynamic convolutions and path aggregation networks, ensures that it can handle a wide range of waste materials in diverse and challenging environments. By improving sorting efficiency, reducing operational costs, and supporting better resource recovery, YOLOv8 contributes to more sustainable recycling practices, advancing both technological innovation and environmental sustainability.

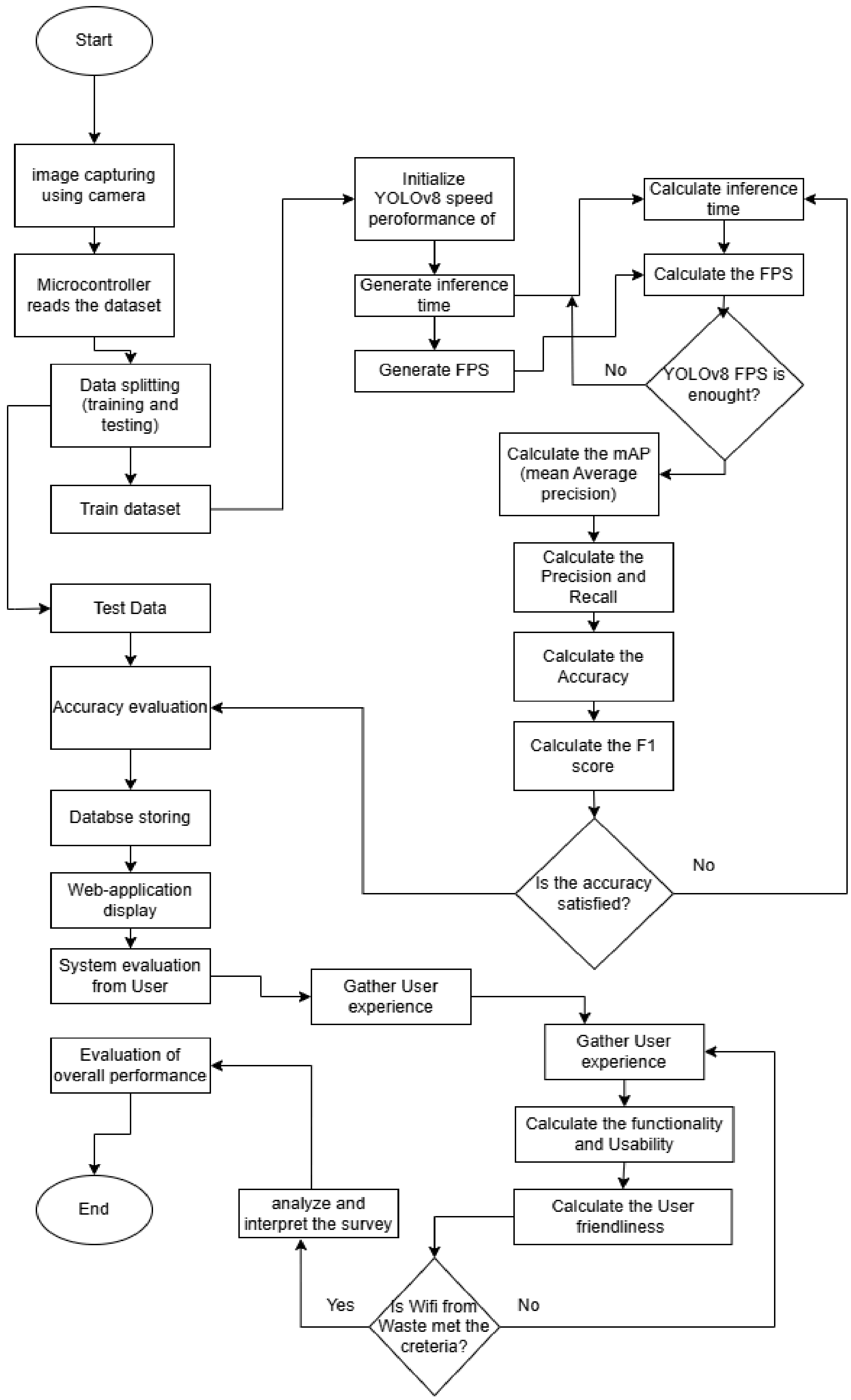

Figure 3-3. YOLOv8 Model

3.2.3 System Architecture

The system operates through a three-layer structure, which includes the hardware layer, the processing layer, and the user interaction layer, as shown in figure 3-4 below. These layers work together to identify recyclable materials, store and analyze relevant data, and provide users with an interactive platform to track their recycling contributions and rewards. The system utilizes modern technologies such as real-time image processing with the YOLOv8 algorithm, MongoDB Atlas, and a web application that optimizes user interaction.

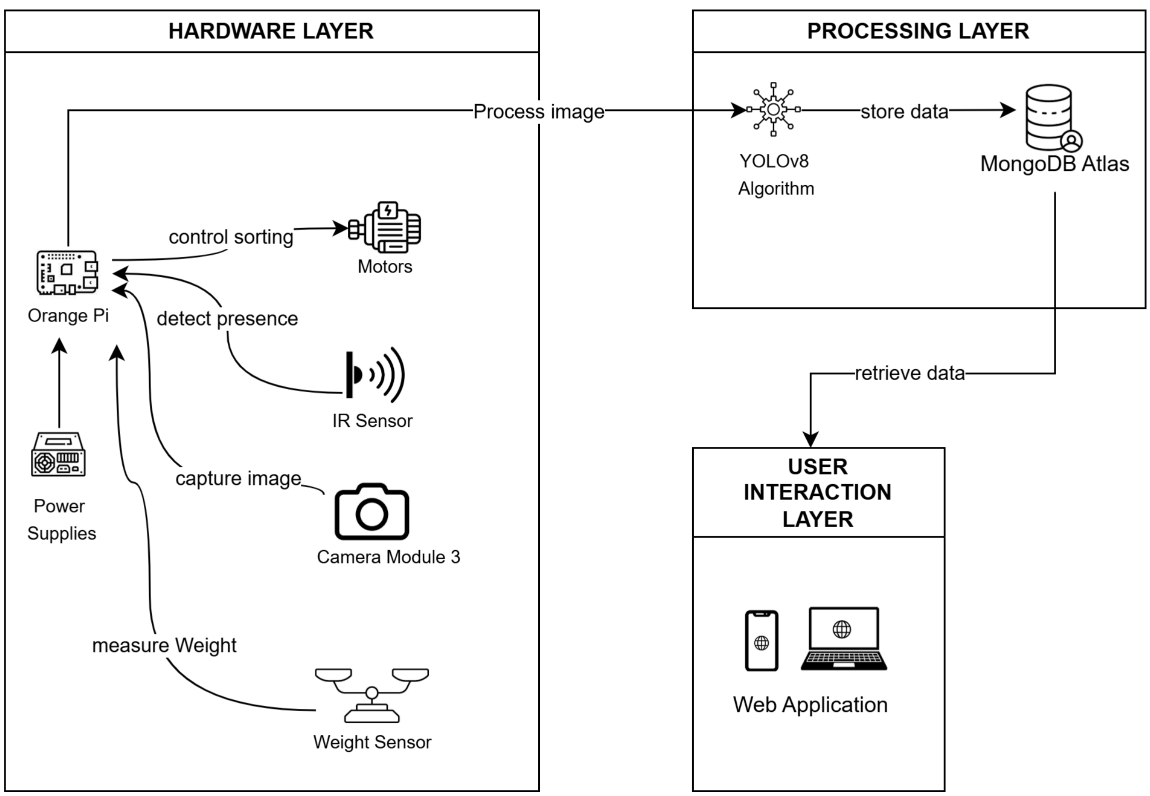

Figure 3-4. System Architecture for WiFi from Waste

The hardware layer of the system includes the essential physical components required for the material identification and sorting process. At its core, the Orange Pi 5 is used to run the YOLOv8 algorithm directly on the device. This setup enables quick and efficient local processing of images captured by the Camera Module 3. The camera scans the materials inserted into the system, and infrared (IR) sensors detect their presence, which triggers the image capture process. The weight sensor is exclusively used to measure the weight of paper, while cans and plastic bottles are assigned reward points based solely on their material type as identified by the algorithm. The materials are sorted into designated bins using motors, which are controlled by the Orange Pi based on the data gathered from the sensors. The system is powered by 12V and 5V power supplies, ensuring consistent performance.

In the processing layer, the YOLOv8 algorithm processes the images captured by the Raspberry Pi camera. This deep learning model is trained to distinguish the plastic bottles and cans. Once the materials are identified, the type of material is transmitted to a cloud-based database. For this purpose, the system uses MongoDB Atlas, which is a distributed and cloud-based database solution. The use of a cloud database allows for reliable data storage and offers scalability as the system potentially expands to support more devices and locations in the future.

Moreover, the user interaction layer is the interface through which individuals engage with the system. Users can access the system via a web application, which allows users to easily view and monitor the points they have accumulated from recycling materials. As users insert recyclable items into the system, the algorithm calculates the corresponding reward points based on the weight and type of material, which are immediately reflected in their accounts.

3.2.4 Agile Methodology

The study will utilize the Agile Methodology as its process model to ensure a flexible, iterative, and user-centric approach to the development of the system. Agile emphasizes collaboration, adaptability, and continuous improvement, making it ideal for integrating IoT technologies and the YOLO object detection algorithm into a functional waste management system.

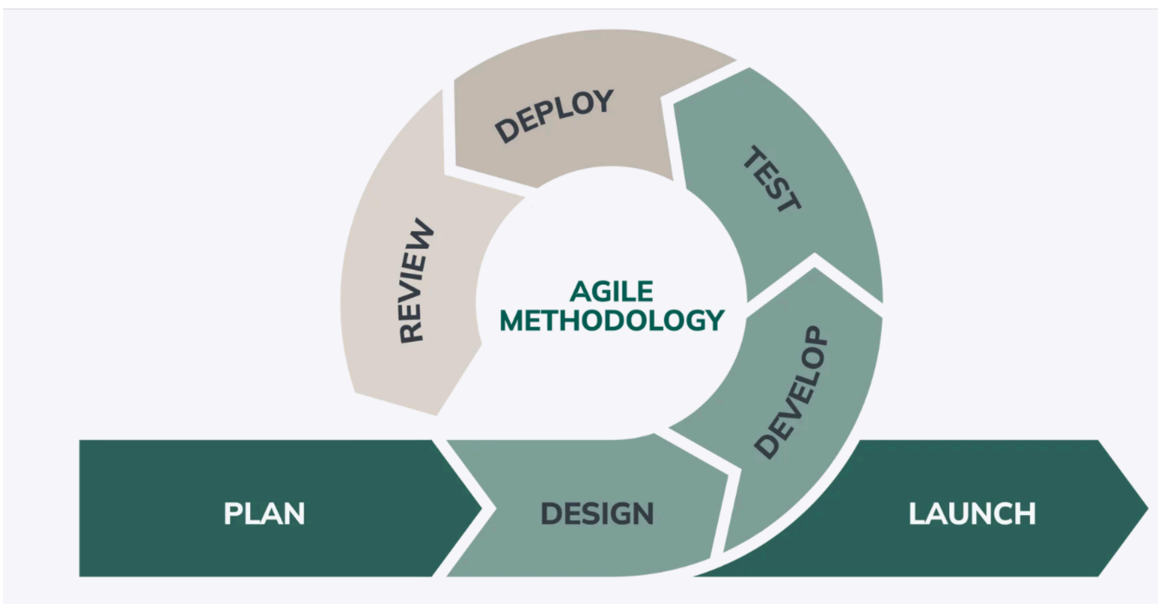

Figure 3-5. Process Model of WiFi from Waste

3.2.4.1 Plan

In the initial phase, the researchers will outline the functionalities of the system. To ensure optimal implementation, the researchers have conducted a comprehensive assessment of the required materials and technologies, focusing on deploying the system effectively in Barangay 3, Malaybalay City.

Furthermore, the hardware component will include a Raspberry Pi 3 Camera Module integrated with the YOLOv8 algorithm to classify and identify various recyclable materials accurately. Additional hardware includes IR sensors, DC gear motors, and a router, which work together to enable seamless functionality. The software component will consist of a dedicated web application that facilitates user interaction and displays information, such as the points earned and the corresponding WiFi rewards.

Additionally, the planning phase includes cost estimation for materials and network components. The total approximation of the cost, including IoT technologies such as Raspberry Pi 3 camera module 3, IR sensors, and DC gear motors is around 20,000 pesos, ensuring the project remains within budgetary constraints.

3.2.4.2 Design

Moreover, the system will comprise two main components namely, hardware and software, The hardware is responsible for detecting, sorting, collecting and segregating recyclable materials while the software handles data processing, reward management, and enabling internet access provision. During this phase, hardware prototypes, such as sensors, cameras, and connectivity modules, will be developed and tested to ensure seamless integration with the YOLO algorithm.

The software design will focus on establishing the system's architecture, including databases for storing user and recyclable material information, as well as developing user-friendly interfaces for both end-users and administrators.

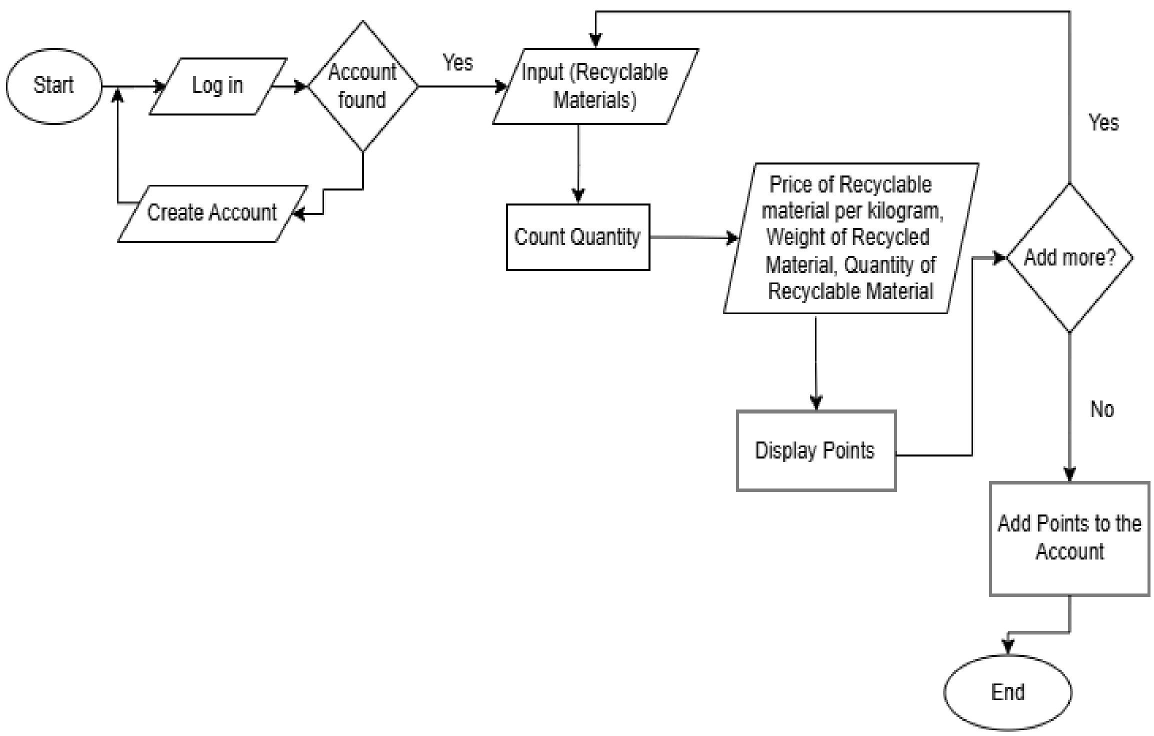

Figure 3-6. System Flowchart

Figure 3-4 illustrates a systematic process for a recycling rewards program. The journey begins with user authentication, where individuals must either log in to an existing account or create a new one if they don't have one. Once authenticated, users can input their recyclable materials into the system, which then undergoes a validation check. If the materials are deemed invalid, the process terminates; however, if valid, the system proceeds to count the quantity of materials submitted.

The system then evaluates whether the quantity meets satisfaction criteria. Upon satisfaction, the system processes several key metrics such as the price per kilogram of the recyclable material, the weight of the recycled material, and the total quantity of recyclable material. These metrics are used to calculate and display points earned by the user. At this stage, users are given the option to add more materials. If they choose to do so, they return to the input phase, and if not, their earned points are added to their account, and the process concludes.

3.2.4.3 Develop

The researchers will focus on developing, constructing and integrating the fundamental components of the system. The hardware will be integrated and adjusted, making sure they are fine-tuned for precise detection and sorting of recyclable materials. At the same time, the YOLOv8 object detection algorithm will be trained and refined to recognize different recyclable items with high accuracy in real-life situations. Furthermore, the software development will entail coding the backend systems for overseeing user data, managing reward points, and facilitating WiFi access. It will also include designing the frontend interfaces for both administrators and users. Every feature will be implemented iteratively in short development cycles, adhering to the Agile methodology. Ongoing testing and debugging will be undertaken throughout this stage to uncover and resolve any issues, guaranteeing a smooth and effective system that fulfills user requirements and functional specifications.

Figure 3-8. User Case Diagram

Figure 3-9. Level 0 Data Flow Diagram

Figure 3-10. IoT Design

3.2.4.4 Test

The testing phase of the system will encompass hardware, software,and integration testing to ensure its functionality and reliability. Hardware testing will focus on the integration of various components, including the Orange Pi 5 4GB, Raspberry Pi 3 Camera Module 3, WiFi Vendo, HX711, and power supplies. These components will be evaluated for their overall performance, compatibility, and reliability, ensuring that the system functions effectively in real-world conditions.

In addition, the software will be assessed according to the standards of ISO/IEC 25010:2023. The survey will focus on quality characteristics that are most relevant to the end user, namely usability, functional suitability, and performance efficiency. Feedback will be gathered through a questionnaire using a 5-point Likert scale, which will measure how well the system meets these criteria.

Furthermore, integration testing will verify the interaction between hardware and software components, ensuring that sensors, cameras, and other devices work together to detect and classify recyclable materials accurately. This testing will confirm that the hardware properly feeds data to the software, which in turn processes the data to segregate materials like plastic bottles and cans. The system's seamless operation will be tested to ensure correct material handling and appropriate reward distribution.

3.2.5 Evaluation

3.2.5.1 YOLO Algorithm Performance Evaluation

The system relies on accurate detection and classification of plastic bottles and cans using the YOLOv8 algorithm. The accuracy rate for the development of the system is a primary focus of the study. The researchers aim to evaluate and experiment with the performance of the YOLOv8 algorithm using established metrics that would serve as the basis for system validation. The experiment's accuracy is significant to ensure reliable material detection and appropriate reward distribution in the recycling program.

$$mAP = \frac{1}{n}\sum_{k=1}^{k=n} AP_k$$

Figure 3-7. mAP Formula

The mean average precision (mAP) is used to assess the accuracy of YOLOv8 algorithm's accuracy in detecting recyclable materials and identifying their type. Figure 3-7 presents the mAP formula used in the study, summarizing the precision-recall relationship by computing the average precision for each material class. A higher mAP score signifies superior accuracy performance, indicating that the YOLOv8 algorithm excels in providing reliable object detection that is crucial for the successful implementation of the recycling management system (Gad & Skelton, 2024).

$$IoU = \frac{TP}{(TP + FP + FN)}$$

Figure 3-8. Intersection over Union Formula

Additionally, Intersection over union (IoU) is a performance metric used to evaluate the accuracy of annotation, segmentation, and object detection algorithms such as YOLOv8. Figure 3-8 shows the IoU formula will be used in this study, measuring the overlap between the predicted bounding box and ground truth bounding box. Predicted bounding boxes that heavily overlap with the ground-truth bounding boxes have higher scores than those with less overlap. This makes intersection over Union an excellent metric for evaluating custom object detectors. (Rosebrock, 2022).

$$\textbf{Precision} = \frac{\textit{True Positives}}{\textit{True Positives} + \textit{False Positives}}$$

Figure 3-9. Precision Formula

Furthermore, precision metric will measure the proportion of correctly detected recyclable materials to the total number of detected objects. It gauges the model's ability to accurately identify positive instances (Koehrsen, 2024). High precision is crucial for reliable point allocation and reward distribution, as it indicates that most of the detected objects are relevant.

$$\textbf{Recall} = \frac{\textit{True Positives}}{\textit{True Positives} + \textit{False Negatives}}$$

Figure 3-10. Recall Formula

In addition, recall will evaluate the proportion of accurately detected recyclable materials relative to the total number of recyclable materials present. This metric is essential for determining how well the system identifies all relevant items, minimizing the chances of overlooking recyclable materials (Koehrsen, 2024).

$$F1 = \frac{2 * (Precision * Recall)}{\left(Precision + Recall\right)}$$

Figure 3-11. F1-score Formula

The F1 score will offer a balanced evaluation by combining precision and recall into a single value. This ensures that both the system's ability to reduce false detections and its effectiveness in identifying all recyclable materials are taken into account (Koehrsen, 2024). By analyzing these metrics, the researchers will thoroughly assess the YOLOv8 algorithm's performance, ensuring the system meets the accuracy and reliability needed to support the recycling program efficiently.

	Actually Positive (1)	Actually Negative (0)
Predicted Positive (1)	True Positives (TPs)	False Positives (FPs)
Predicted Negative (0)	False Negatives (FNs)	True Negatives (TNs)

Figure 3-13. Confusion Matrix

Moreover, the confusion matrix will be used to describe the performance of a classification model by comparing the predicted classification with the actual (Impact of Confusion Matrices: Key Case Studies Explored, n.d). It provides a detailed breakdown of true positives, true negatives, false positives, and false negatives to assess the accuracy and reliability of the model. A confusion matrix, as shown in Figure 3-12, will be a key tool for evaluating performance of the proposed system which detects the recyclable materials using the YOLO algorithm to ensure it meets the requirements of the recycling program effectively.

The detection time (inference time) refers to the time the model takes to analyze a single image and produce a detection result. It plays a crucial role in evaluating the real-time performance of the algorithm in the system. Lower detection times are essential for ensuring the system operates efficiently, especially in high-activity scenarios. To measure this, the average inference time is calculated using multiple test images, providing an accurate assessment of the system's responsiveness. Factors such as hardware performance, model complexity, and input data can affect this metric, making it a key indicator of the system's ability to meet real-time detection requirements (Mwitta et al., 2024).

3.2.5.2 Evaluation of Web Application Effectiveness

The effectiveness of the system will be evaluated using the standards of ISO/IEC 25010:2023. This international standard defines a product quality model applicable to ICT (Information and Communication Technology) products and software (ISO/IEC 25010:2023, n.d.). The evaluation will focus on the most relevant quality characteristics of the system, specifically usability, functional suitability, and performance efficiency. Additionally, feedback will be gathered from the end users to evaluate these aspects effectively.

The researchers will utilize a 5-point Likert scale developed by social psychologist Rensis Likert in 1932. The survey questionnaire will include a series of questions, ranging from "poor" to "excellent." The interpretation of the results is shown in Table 3-3 below. In addition, the evaluation will be tailored to each evaluation aspect. For instance, terms such as "Poorly Usable" and "Excellent Usability" will be used for usability in order to signify its relevance to the assessed aspect. Moreover, data collected through the Likert scale will be analyzed by averaging responses for each criterion.

Table 3-3. Likert Scale Interpretation

Scale	Range	Quality Interpretation
1	1.00-1.80	Poor
2	1.81-2.60	Needs Improvement
3	2.61-3.40	Moderate
4	3.41-4.20	Good
5	4.21-5.00	Excellent

4 RESULTS AND DISCUSSION

4.1 Results by phase of study

Name the phases of your study and give the results. Have as many headings as necessary depending on the number of experiments or studies you did. Provide the discussions. It may have one-to-one correspondence with your specific objectives.

4.2 Verification studies

The headings above are only suggestive. Follow what is appropriate for your research work.

5 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary

Provide a rather concise summary of the research work.

5.2 Conclusions

The conclusions are direct statements that would prove the achievement of the specific objectives. The conclusions should have one-to-one correspondence to the specific objectives, i.e. if you have 4 specific objectives (a to d) then you should have 4 conclusions (1 to 4).

5.3 Recommendations

Number the recommendations and start the statement with an action word.

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APPENDICES

1. <Appendix A:> <Title>

Place your appendices here. Please be sure that these have been referenced in the body of document.

CURRICULUM VITAE

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Name:
Address:
Contact Number:
Email Address:

Educational Attainment:

Membership in Organization:

Skills: