Image Processing on Plastic Bottle Reverse Vending Machine to Enhance Community Plastic Waste Management

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Abstract— The problem of plastic waste is being addressed in a variety of ways, ranging from manual waste sorting to reverse vending machines. On the other side, businesses are becoming increasingly concerned about waste management. Several ways to producing reverse vending machines have been tested, including the use of plastic sensors. However, the findings were unsatisfactory due to imprecise detection. This study looks into the use of ESP32-Cam combined with machine learning for high-precision plastic bottle detection in reverse vending machines. It is envisioned that high-precision plastic bottle detection would be used in reverse vending machines. It is intended that by providing an incentive for each identified plastic bottle, people will be motivated to collect plastic bottles and deposit them into reverse vending machines, thereby supporting digital humanities through enhanced waste management practices.

Keywords— *digital humanities, esp32-cam, iot, machine learning, plastic bottle, reverse vending machine*

I. INTRODUCTION

Currently, environmental problems have become a serious concern for global civilization. One topic that has received international attention is waste management [1]. This is caused by a lack of community participation and responsibility in waste management [2]. The first and very crucial step in waste management is waste sorting, which aims to prevent negative impacts on the environment. This process involves sorting waste by kind, such as organic waste, inorganic waste, and recyclable materials. If waste is disposed of inappropriately, it will damage the environment and spread harmful gas emissions [3]. By implementing proper waste management practices and adopting decentralized waste management and treatment methods, the negative impacts can be significantly reduced [4]. In addition, waste segregation helps facilitate the recycling process, allowing materials that have economic value to be reused. Through collective efforts in waste sorting, we not only keep the environment clean but also contribute to protecting the ecosystem and human health from the dangers of pollution and contamination.

In 2023, Indonesia will produce around 24,707,862.19 tons of waste, of which 18.7% is plastic waste. The remaining waste is generated from various sources, including households 44.6%, traditional markets contributing 20.4%, commercial centers contributing 16.9%, and regional areas 5.7% [5]. These figures highlight a significant issue in waste management within the country, particularly in the realm of waste sorting. Despite the substantial amount of waste produced, the implementation of effective waste sorting techniques remains suboptimal. This lack of efficient sorting methods leads to increased environmental pollution, higher landfill usage, and greater greenhouse gas emissions. The diverse origins of the waste,

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spanning households, markets, and commercial centers, underscore the complexity of the waste management challenge in Indonesia. Therefore, it is imperative to enhance waste sorting practices across all sectors to mitigate the adverse environmental impacts and promote a more sustainable approach to waste management.

In Indonesia, plastic is a material that people often use for many purposes, for example, drinking bottles [6]. Although it is a versatile and practical material, its use can cause environmental problems due to its high resistance to degradation [7]. Plastic takes hundreds of years to fully break down [8]. During this process, plastic degrades into microplastics, which can enter the human food cycle and cause health risks. Although not all sizes can enter the human body, researchers have some assumptions that microplastics with a size of less than 20 µm can enter human organs. This can cause immunosuppression in the human body [9].

To address these problems, one option that may be adopted is the usage of Reverse Vending Machines (RVM). RVM is an innovative device designed to collect recyclable items more effectively, Increase the recycling process enhance waste management [10] [11]. This machine works by accepting recyclable items, such as plastic bottles, and providing incentives to users, such as money or vouchers, in return [12] [13] [14]. The most important uses of RVM is handling plastic bottles, which are a common and hazardous type of waste for the environment. Plastic bottles are often difficult to recycle efficiently, and if not properly managed, they can pollute oceans and land, endanger wildlife, and contribute to human health problems. Several research efforts focus on developing RVM prototypes with more advanced sorting methods. This system is designed to recognize the material type of an item using a combination of three types of sensors: capacitive, inductive, and load sensors [15]. Capacitive sensors are used to detect non-metal materials, inductive sensors to detect metals, and load sensors for measuring the weight of the material. However, existing RVM machines still have limited capabilities, as they can only detect whether the inserted material is plastic or not, requiring further development to enhance the effectiveness and efficiency of this system. With more advanced technological development, RVMs have great potential to serve as an effective solution in tackling waste management issues, increasing recycling rates, and preventing the dangers of microplastics in Indonesia.

Based on previous research, there is ample room for innovation in developing more accurate and efficient Reverse Vending Machines (RVMs). This study will explore various ways to create more advanced RVMs by integrating ESP32 camera technology with image processing. By utilizing machine learning, the capacity of RVMs to detect and process recyclable materials can be significantly enhanced. With proper training, RVMs will be able to accurately identify different types of plastic bottles, thereby minimizing sorting errors. Additionally, this technology enables real-time data processing, ensuring that detection and identification results are displayed immediately without delay. This strategy will not only improve the effectiveness of plastic waste sorting but also contribute significantly to global efforts help mitigate waste's damaging impact on the environment. Thus, integrating this technology not only improves the technical performance of RVMs but also supports sustainability and environmental preservation goals.

II. CONCEPT OVERVIEW

2.1 System Description

The Reverse Vending Machine (RVM) system uses image processing technology, which allows the machine to detect and verify the kind of bottle being entered. The system uses cameras and image recognition algorithms to correctly determine between plastic bottles and other things. This technology not only guarantees that only appropriate plastic bottles are delivered, it also improves the overall efficiency of the sorting process. The use of this image processing technology also helps to reduce human error and increase processing speed.

To assist in building this system, the author used the community-based application, which was designed to make it easier for students from Soegijapranata Catholic University to recycle plastic bottles. The process begins when the user scans the barcode in the application. This barcode reader will read the user's ID and identify them in the system. After the user ID is verified, the application will invite the user to insert the plastic bottle into the machine provided. When users feel they have included all the plastic bottles they want to recycle, they can press the "finish" button located on the machine's screen. After that, the system will automatically calculate how many points the user gets from the total bottles that have been entered, and which will then be added to the user's account on the application.

2.2 Main System Components

The plastic bottle sorting machine comprises several key components that work together to ensure efficient and accurate sorting of plastic bottles. Each component contributes significantly to the entire system, from picture capture and analysis to tracking user behavior and allowing user engagement. By integrating advanced hardware and software technologies, the system achieves high reliability and performance. Below are the main components of the system:

1. Barcode Scanner

Figure 1. Barcode Scanner

The barcode scanner is a data collecting instrument that reads and decodes printed barcodes on various goods. This gadget lights the barcode with a light source, usually a laser or LED, and then captures the reflected light patterns using a sensor. These patterns are subsequently transformed into electrical signals that are analyzed by a decoder to recover the encoded data. Barcode scanners are available in a variety of configurations, including portable, fixed-mount, and mobile devices, each tailored to a certain environment and application. To operate this machine, the user must first scan the barcode in the community-based program with a barcode scanner.

2. Community-based Application

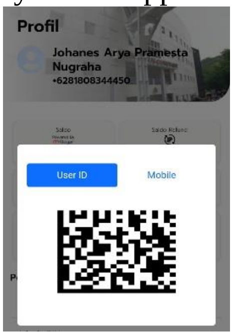

Figure 2. Community-based Application

This is an application owned by the Faculty of Computer Science, Soegijapranata Catholic University. This application is a medium for entrepreneurship and information for faculties. This application provides various useful features for its users, including the latest news and information that can be easily accessed to find out the latest developments on and around campus. The hotline feature allows users to contact important services quickly and efficiently. Community service facilitates interaction and collaboration among members of the faculty community. Additionally, the merchant feature provides a platform for users to buy and sell products, while the billing feature helps in managing and paying various existing bills. In emergency situations, the emergency feature provides quick access to the help needed. Another features is user can makes transactions easier with the QRIS, allowing users to make digital payments easily and safely.

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Each user in this application has a unique QR ID, which is used for various identification and transaction purposes, making this application very functional and practical for daily activities in the faculty environment.

3. Edge Impulse

Figure 3. Edge Impulse

Edge Impulse allow developers to automate the ideal algorithm for their application [16]. is a website specifically designed to facilitate the creation and implementation of machine learning solutions on edge devices. The platform allows users to create, train, and deploy machine learning models straight to edge devices such as IoT sensors, microcontrollers, and mobile devices. With Edge Impulse, users can collect data directly from their devices, preprocess the data, and use advanced tools to build efficient machine learning models. One of the key advantages of Edge Impulse is its ability to perform inference directly on edge devices, meaning data can be analyzed and processed in real-time without the need to send data to the cloud, thereby reducing latency and increasing data privacy. This platform also provides various additional features such as analytical dashboards, data visualization, and easy integration with various hardware.

4. Esp32-cam

Figure 4. Esp32-cam

Esp32-cam is one of the Esp32 boards that includes a camera module, making it an excellent choice for image capture and processing applications [17]. This compact and powerful board combines the Esp32 microcontroller's capability with an integrated OV2640 camera, making it an affordable choice for a variety of projects. The Esp32-cam has both Wi-Fi and Bluetooth connection, allowing for remote monitoring and control, meaning it's critical for current IoT applications. Its adaptability allows it to be used in a variety of settings, including security systems, home automation, and environmental monitoring. The Esp32-cam can be used to record high-resolution photographs of bottles, which are then correctly identified and sorted using powerful image recognition algorithms.

5. Wemos

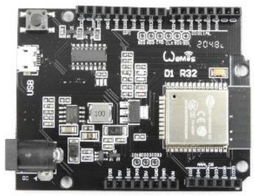


Figure 5. Wemos

WeMos is an ESP32 based development board popularly used in Internet of Things (IoT) projects. This board combines the power of an ESP32 microcontroller with Wi-Fi and Bluetooth connectivity, making it ideal for applications that require wireless communications. WeMos is also equipped with a large number of GPIO pins, enabling integration with a variety of sensors and actuators. Additionally, the board is compatible with the Arduino development environment, making it easy for users to program and upload code via the Arduino IDE. With high processor speed and large enough memory, WeMos is able to handle complex tasks such as real-time data processing and simultaneous device control [18].

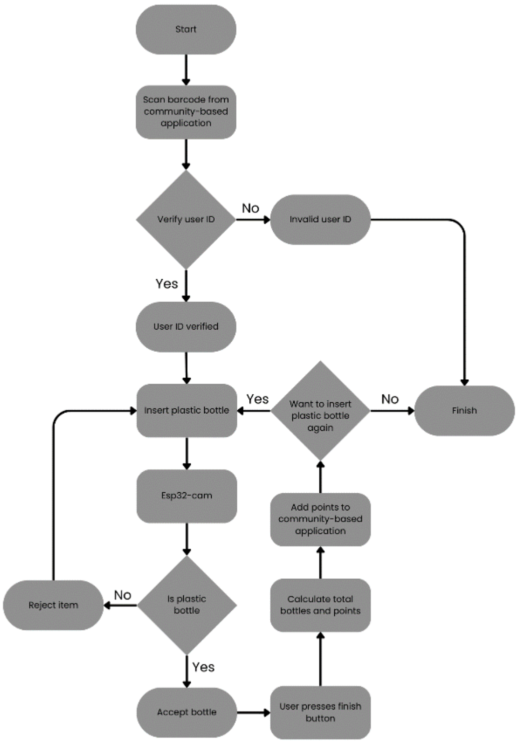


Figure 6. Flowchart

This flowchart illustrates the process of using a community-based application to recycle plastic bottles. The process begins with the user scanning a barcode using the application. After scanning the barcode, the system verifies the user's ID. If the user ID is invalid, the process stops. If the user ID is valid, the user is allowed to proceed and insert a plastic bottle into the system. The Esp32-cam then determines if the inserted object is a plastic bottle. If the item is not a plastic bottle, it is refused, prompting the user to insert another plastic bottle. The system accepts plastic bottles. The user then presses the finish button, and the system calculates the total number of bottles inserted and the points earned. These points are then added to the community-based application. If the user wants to insert another plastic bottle, the process returns to the step of inserting a plastic bottle. If not, the process is finished.

III. IMPLEMENTATION

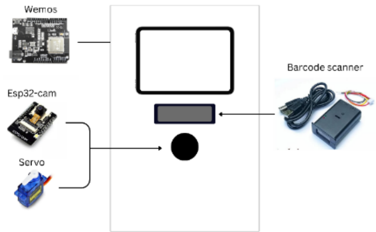


Figure 7. Diagram of Implementation

This diagram is a representation of a plastic bottle sorting machine that uses image processing technology to increase efficiency and accuracy in the sorting process. The main components of this machine include Wemos, ESP32-CAM, servo, and barcode scanner, all of which work synergistically to achieve this goal. Wemos functions as the main controller that manages communication between other components, ensuring precise and responsive coordination. ESP32-CAM is used to capture images of plastic bottles, which are then analyzed using advanced image processing algorithms to determine the type of bottle based on its visual characteristics. Once the type of bottle is determined, the servo is tasked with moving the bottle to the trash can. In addition, a barcode scanner is used to read the user's ID in order to send points from the total bottles entered into the machine.

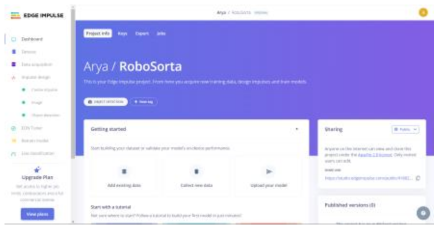


Figure 8. Main Page of Edge Impulse

The process of carrying out image processing using a website called Edge Impulse involves several important steps starting from data acquisition, collecting training data, and training the machine learning model. First, users must upload or collect the image dataset they want to analyze into the platform. Edge Impulse provides a variety of tools to help with this process, such as capturing images of plastic bottles on the device and capturing images of plastic bottles directly via other devices.

Figure 9. The Process of Collecting Data on Plastic Bottles

Each bottle in the dataset is given a corresponding bounding box and label to ensure that the model can recognize and classify the bottles correctly. After the data is collected, the pre-processing storage stage is carried out by adjusting the width and height of the image through a resizing process, adding processing blocks and learning blocks needed for further analysis, and changing the color depth to RGB.

After the pre-processing stage is complete, the next step is to carry out a training set to generate the object model. This training process involves the use of machine learning algorithms applied to processed data to identify relevant patterns and features in bottle images. After the model is formed and tested to ensure accuracy and performance, the final step is to deploy the model to the Arduino library. By implementing the model directly on the hardware, the plastic bottle sorting system can operate in real-time, utilizing image processing capabilities to efficiently classify and group bottles by type.

IV. DISCUSSION

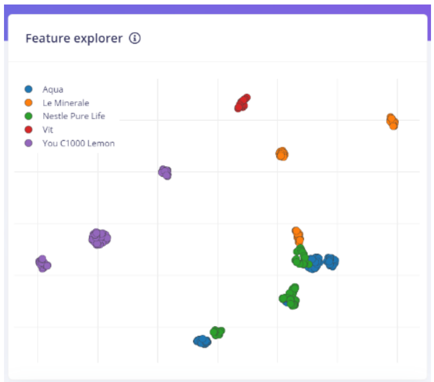
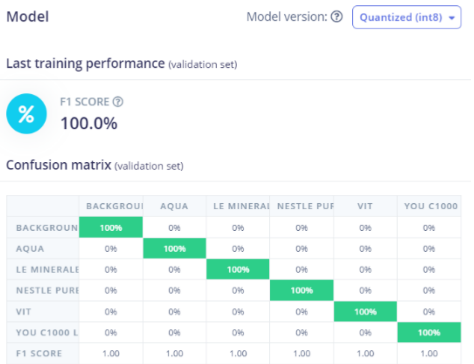


Figure 10. Feature Explorer

The feature explorer is an edge impulse visualization tool whose job is to understand the distribution of samples that have been extracted from the image. Groups with several colors indicate bottle samples, such as blue for Aqua bottles, orange for Le Minerale bottles, green for Nestle bottles, red for Vit bottles, and purple for You C1000 Lemon bottles. Groups of points with the same color indicate that the samples have similar features and are grouped together by the model. From this grouping, it can be concluded that this model can identify and classify plastic bottles with high accuracy.



	BACKGROUI	AQUA	LE MINERAI	NESTLE PUF	VIT	YOU C1000
BACKGROUN	100%	0%	0%	0%	0%	0%
AQUA	0%	100%	0%	0%	0%	0%
LE MINERALE	0%	0%	100%	0%	0%	0%
NESTLE PURE	0%	0%	0%	100%	0%	0%
VIT	0%	0%	0%	0%	100%	0%
YOU C1000 L	0%	0%	0%	0%	0%	100%
F1 SCORE	1.00	1.00	1.00	1.00	1.00	1.00

Figure 11. Confusion Matrix

The model used is a version that has been quantized to int8 format for computational efficiency. This model earned an F1 Score of 100.0% on the validation set, which is a precision-recall measure combined. This flawless F1 Score result indicates that the model has very high precision and recall, implying that it can reliably categorize plastic bottles without making any errors. The confusion matrix in this picture shows the number of correct and wrong predictions produced by the model for each type of plastic bottle. The rows and

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columns in this matrix represent the actual and predicted classes, with each cell showing the predicted percentage. For example, for the background class (BACKGROUND), 100% of the background images were correctly classified as backgrounds, and none were incorrectly classified as other plastic bottles. The same goes for Aqua, Le Minerale, Nestle Pure Life, Vit, and You C1000 Lemon bottles, where 100% of each bottle was classified correctly without any errors.

The last row of the confusion matrix displays the F1 Score for each class, with a perfect score of 1.00 (or 100%) for all classes: background, Aqua, Le Minerale, Nestle Pure Life, Vit, and You C1000 Lemon. The F1 Score for each class is derived as the harmonic average of accuracy (the model's ability to avoid classifying negative samples as positive) and recall (the model's ability to accurately categorize all positive samples). The perfect F1 Score value for each class shows that this model has extraordinary performance in classifying all types of plastic bottles tested, without any prediction errors. Overall, this image illustrates that the machine learning model used is very accurate and effective in its classification task, as shown by the perfect F1 Score value and the absence of classification errors in the confusion matrix. These results reflect the good quality of training and data, as well as the model's ability to capture relevant features to differentiate each type of plastic bottle.

Table 1 Input Type Trial

Type of Input	Results				
	Trial 5	Trial 10	Trial 15	Trial 20	Trial25
Aqua Bottle	✓	✓	✓	✓	✓
Le Minerale Bottle	✓	✓	✓	✓	✓
Nestle Pure Life Bottle	✓	✓	✓	✓	✓
Vit Bottle	✓	✓	✓	✓	✓
You C1000 Lemon Bottle	✓	✓	✓	✓	✓
Hard disk Case	✕	✕	✕	✕	✕
Tissue	✕	✕	✕	✕	✕
Aluminium Bottle	✕	✕	✕	✕	✕
Tin Can	✕	✕	✕	✕	✕

Table 1 shows the results of 25 experiments with various types of input, including plastic bottles, tin bottles, tissue paper, aluminum bottles, and hard disk case. From the experiments carried out, it was discovered that all types of plastic bottles were successfully detected, while hard disk cases, tissue and aluminum bottles were not detected by the system. This shows that the current RVM configuration is very effective in identifying plastic bottles. The system's inability to detect non-plastic items shows the machine's accuracy in focusing only on plastic bottles. By successfully differentiating plastic bottles from other materials, RVM ensures that only recyclable materials are accepted, thereby simplifying the recycling process and reducing the possibility of contamination from non-recyclable materials. This focused approach increases RVM's efficiency and reliability in managing plastic waste, in line with the aim of supporting sustainability and environmental preservation goals.

V. CONCLUSION

The reverse vending machine can recognize plastic bottles with 100% accuracy and does not detect objects other than plastic bottles. This high level of precision ensures that only recyclable materials are processed, thereby significantly reducing contamination from non-recyclable waste. Leveraging advanced image processing and machine learning techniques, the system enhances the efficiency and reliability of plastic waste sorting processes. Additionally, by providing incentives for each correctly identified bottle, the system encourages greater public participation in recycling efforts. This approach not only streamlines waste management operations but also fosters a culture of environmental responsibility among users. The successful integration of ESP32-CAM and image processing models demonstrates the potential of technology-driven solutions to address complex environmental challenges effectively. By implementing such precise and reliable systems, we can improve overall waste management practices, contributing to environmental sustainability and promoting a healthier, cleaner future.

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