YOLOv8n– Radio Frequency Identification (RFID) Bottle Sorting with Eco-Pay for Sustainable Society

Dwi Hastuti[1], Wildan Surya Wijaya[2], Ahmad Adi Wicaksono[3], Maharani Wisudawati Swista[4], Yitno Utomo[5], Manik Ayu Titisari[6]

[1.2.3.4]Electrical Engineering Study Program, Universitas PGRI Adi Buana Surabaya,Surabaya, Indonesia

[5.6]Industrial Engineering Study Program, Universitas PGRI Adi Buana Surabaya,Surabaya, Indonesia

Jl. Dukuh Menanggal XII No.4, Surabaya 60234

E-mail: dwi.hatuti@unipasby.ac.id, wildansurya@unipasby.ac.id, ahmadadi.wcksn@gmail.com, swistamaharani@gmail.com, yitno@unipasby.ac.id, manikayu@unipasby.ac.id

***Abstract*— The increasing volume of plastic waste requires innovative solutions that integrate technology with sustainable economic incentives. This study presents the development and evaluation of the ECO-PAY system, an automated plastic bottle waste management system that combines YOLOv8n-based object detection with Radio Frequency Identification (RFID) user identification to support circular economy implementation. The system was designed to identify recyclable plastic bottles in real time, authenticate users, and allocate reward points automatically for each valid disposal transaction. Experimental results show that the YOLOv8n model achieved a maximum confidence score of 93.78% with an average detection accuracy of 72.18% in detecting plastic bottles. System performance testing demonstrated stable real-time operation with a frame rate ranging from 6.58 to 14.91 FPS, enabling fast and continuous transactions suitable for public use. In addition, all transaction data, including user identity, object type, and accumulated points, were successfully recorded in a community-based Excel database in a structured and transparent manner. These findings indicate that the ECO-PAY system is technically feasible, reliable, and effective as a smart waste management solution, contributing to sustainable environmental practices and the practical realization of a circular economy model.**

Keywords— ECO-PAY system; YOLOv8n, RFID

I. INTRODUCTION

Plastic waste has become one of the most pressing environmental issues in Indonesia. According to data from the Ministry of Environment and Forestry, Indonesia generates approximately 64 million tons of waste per year, with more than 11% consisting of plastic waste [1]. Most of this plastic waste is not managed effectively and ends up in landfills, drainage systems, rivers, and even the oceans. This condition not only degrades environmental quality but also threatens marine ecosystems and human health, as plastic requires hundreds of years to decompose [2]. Low public awareness regarding waste sorting at the source is a primary cause of plastic waste accumulation. Most people still mix organic and inorganic waste without a sorting process, making recycling opportunities extremely low. Furthermore, the utilization of digital technology, the Internet of Things (IoT), and Artificial Intelligence (AI) in community-level waste management systems remains very limited [3].

In fact, the economic potential of plastic waste management is substantial if conducted systematically and integrated with a circular economy approach. Several previous studies indicate that the application of IoT technology and digital image processing can improve efficiency in waste management. Research by [4] in the E3S Web of Conferences explained that an IoT-based smart waste management system enables real-time monitoring of waste volume and conditions using wireless sensors. Another research by [5] in Paper Technoscientific applied the You Only Look Once (YOLO) model to automatically detect and classify types of waste with high accuracy. Additionally, research by [6] proved You Only Look Once (YOLO) capability in detecting floating plastic waste on water surfaces with resilience to lighting variations.

Eco-pay is an electronic payment system designed to facilitate the non-cash transaction process by utilizing digital technology. These systems typically integrate the user's Radio Frequency Identification (RFID) card, application, or digital identity so that the payment process can be done quickly, practically, and securely without using physical money.

In its implementation, Eco-pay works by connecting user identities with electronic payment media, such as Radio Frequency Identification (RFID) cards or digital accounts stored in the system's database. When a user makes a transaction, for example by attaching an Radio Frequency Identification (RFID) card to an RFID reader, the system will read the card's UID, then match it with the user's data stored on the server. If the data is valid and the balance is sufficient, then the system will automatically process the payment and record the transaction.

However, most of these studies still focus on object detection and classification without providing a direct contribution to community economic empowerment. There is limited research integrating AI-based visual recognition systems with digital incentives as a form of appreciation for waste-sorting behaviour. This is the urgency and novelty of this research [7]. To address these challenges, an innovation called the "Bottle Waste Sorting Machine Based on YOLOv8n (You Only Look Once version 8 nano) and RFID" was developed. This system is designed to detect, sort, and exchange plastic bottle waste for digital economic points that can be converted into monetary value. You Only Look Once version 8 nano (YOLOv8n) technology is utilized to identify plastic objects quickly and accurately, while Radio Frequency Identification (RFID) is used to recognize user identities automatically. Every bottle deposited is counted and valued at Rp100 per object, which is then stored in a community database [7]. With the concept of Green Robotics, which integrates artificial intelligence, robotics, and incentive systems, this machine functions not only as an automatic sorting device but also as a medium for environmental education and local economic empowerment. Through this approach, plastic waste management is expected to shift from being a burden into an economic opportunity that supports the achievement of the Sustainable Development Goals (SDGs), particularly Goal 11

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(Sustainable Cities and Communities) and Goal 12 (Responsible Consumption and Production) [8].

II. MATERIALS AND METHODS

The methodology of this research is systematically structured to ensure that each implementation stage is conducted efficiently and yields optimal results. The research process initiates with problem identification and the establishment of research objectives, which serve as the foundation for designing the ECO-PAY system an automated plastic waste exchange tool integrated with You Only Look Once version 8 nano (YOLOv8n) and RFID technology [9]. Following this, the system architecture is designed alongside the preparation of necessary materials and hardware components. Subsequently, plastic bottle image data is collected to serve as the training dataset for the detection model. The final stages encompass training the You Only Look Once version 8 nano(YOLOv8n) model to accurately recognize plastic bottle types and integrating the system with RFID modules and data loggers for seamless transaction recording [10].

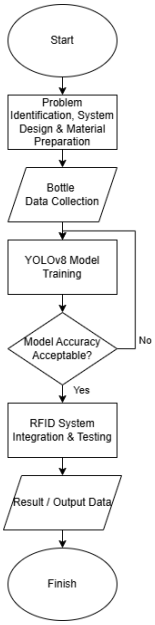


Fig. 1. Research Methodology Flowchart

The flow of the research can be seen as shown in fig.1 This research begins with problem identification and the definition of research objectives, focusing on plastic waste issues and the development of smart technology-based solutions. The next phase involves system design and material preparation, which includes the integration of a webcam, Arduino, Mini PC, Radio Frequency Identification (RFID) module, servo motors, and a data logger, all managed through Python and OpenCV software.

Subsequently, image data collection of plastic bottles across various types and lighting conditions was conducted to train the You Only Look Once version 8 nano(YOLOv8n) model [11]. This data was annotated using Labelling prior to the training process to ensure a detection accuracy exceeding 90%. Once the model was trained, the RFID system and data logger were integrated to record user identity, bottle count, timestamps, and economic value in a comma separated values (CSV) format.

The following stage consists of system testing, covering evaluations of detection accuracy, processing speed, and data storage reliability, including field trials with the community [12]. Based on these test results, system evaluation and refinements were carried out to enhance the tool's effectiveness and reliability. The research concludes with the development of a final prototype and a comprehensive research report, aimed at providing an innovative solution to support the circular economy and increase public awareness regarding sustainable plastic waste management [13].

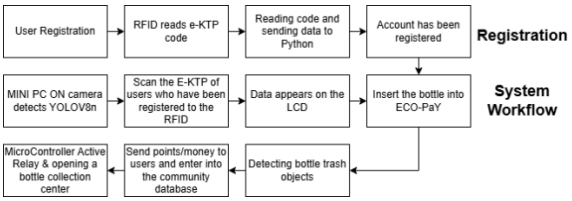


Fig. 2. Workflow Flowchart.

The ECO-PAY System is shown in fig 2. an Internet of Things (IoT) based innovation that integrates RFID technology, You Only Look Once version 8 nano (YOLOv8n) detection cameras, and microcontrollers to manage plastic waste digitally. It utilizes a point-based incentive system linked to the user's identity Radio Frequency Identification (RFID). The system's operation is divided into two primary components: the registration process and the system workflow.

A. Registration Process

In the initial stage, users register their electronic ID cards to be recorded as authorized system users. The RFID module reads the unique identification code from the RFID card and transmits the data to a Python-based database, which then securely stores the user's identity. Upon successful entry, the system displays the status "Account Registered," indicating that the user is now ready to utilize the ECO-PAY system.

B. System Workflow

The system in Eco pay can be seen in fig.3. Block diagram system Once registered, the user rescans their ID card using the RFID reader. The stored user data is retrieved and displayed on the liquid crystal display (LCD) screen, signaling a successful verification. Following authentication, the user places a plastic bottle into the ECO-PAY device.

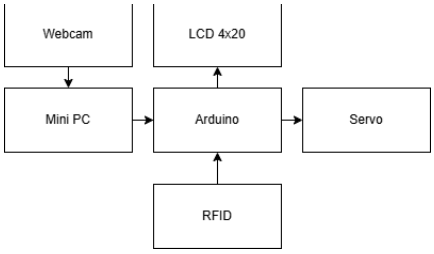


Fig. 3. Block diagram system

A camera, managed by a Mini PC running the You Only Look Once version 8 nano (YOLOv8n) algorithm, detects and identifies the type of waste deposited. Upon successful detection of the waste object [6], the microcontroller activates a relay to automatically open the bin cover. The

system then awards digital points to the user based on the quantity or type of waste collected. These points are automatically recorded in the community's Excel database, which serves as a centralized platform for monitoring, user data management, and the administration of incentive programs.

III. Results and Discussion

This chapter presents the results of the implementation and an in-depth analysis of the performance of the Plastic Bottle Waste Sorting Machine that has been developed. The primary focus of this study is to examine how the integration of a computer vision system based on You Only Look Once version 8 nano (YOLOv8n) and digital identification through Radio Frequency Identification (RFID) can operate synchronously to support the circular economy movement within the community.

The success of this system is measured by its ability to automate the waste sorting process, which has traditionally been carried out manually, while simultaneously providing direct economic value to users. Through an appropriate technology approach, this machine functions not only as a waste sorting device but also as an educational and motivational instrument that encourages public participation in achieving environmental sustainability. The following analysis elaborates on the entire process, starting from user identity management to the automatic reward distribution mechanism.

A. User Registration Stage

The registration stage is a crucial initial step to ensure that all forms of community participation are accurately documented in the community database which can be seen in Table 1. This process begins with identity registration, during which users register their national identification card to be digitally recorded as their system identity. Next, the RFID device acquires the identification code by reading the unique identifier (UID) embedded in the user's ID card. The acquired code is then processed during the data integration stage, where it is incorporated into the Python programming data and specifically linked to the user's profile. Once the entire synchronization process is successfully completed, the account is officially registered, and the user can begin utilizing the services provided by the ECO-PAY machine.

User identity data in the system is obtained from the registration process which includes several important attributes, namely Population Identification Number, name, place of birth, gender, sub-district, marital status, nationality, and RFID UID. An example of data used in this study is a user with a 3504051 NIK in the name of Ahmad Adi who was born in Tulungagung, is male, domiciled in Kauman District, has unmarried status, and has Indonesian citizenship . In the developed system, the user's identity is linked to the RFID card UID 032339C2B46680 which functions as a unique identity for the authentication process on RFID-based devices. When the RFID card is scanned on the reader, the system will match the readable UID with the data stored in the database. If the UID matches the registered data, then the system will recognize the user and grant access according to the functions that have been defined on the system.

B. Performance Analysis of the YOLOv8n Algorithm in Object Detection

The use of the You Only Look Once version 8 nano (YOLOv8n) model in the ECO-PAY system provides high efficiency in real-time plastic bottle image processing Testing and interface display can be seen in Fig 4. The selection of the nano variant is based on the requirement for fast detection on a Mini PC with limited computational resources, while still maintaining an optimal level of accuracy in distinguishing valid plastic bottles from other waste objects. During testing, the algorithm was able to detect objects immediately after users inserted bottles into the machine, thereby triggering the system to proceed automatically to the point allocation stage and relay activation.



Fig. 4. Performance Analysis of the YOLOv8n Algorithm in Object Detection

C. Integration of RFID and Excel-Based Database for Data Transparency

The RFID-based identification system utilizing ID card ensures that each point transaction is personal and secure. The use of a community Excel spreadsheet as the database provides convenience for system administrators to periodically monitor waste collection statistics without requiring complex server infrastructure.

The recorded data include user identity, item type, and the number of points earned after the waste object is detected and successfully classified by the system, as can be seen in Table 2. This approach creates a significant level of transparency that is essential to the implementation of a circular economy model, where community members can clearly observe and understand their tangible contributions to environmental sustainability as well as the gradual accumulation of their economic value through recycling activities. Furthermore, the integration of this identification and data recording mechanism strongly supports the Eco-Pay incentive scheme by enabling accurate, systematic, and real-time tracking of individual contributions made by each user. Each verified transaction not only reinforces user accountability and participation but also facilitates a fair and transparent point distribution mechanism that can later be converted into digital economic value, financial incentives, or community-based rewards. By effectively linking waste sorting activities with a transparent and technology-based incentive system, the platform encourages sustained public participation, strengthens community trust in the recycling and waste management process, and ultimately promotes long-term behavioral change aligned with the fundamental principles of environmental sustainability and a circular economy framework.

TABLE 1. INTEGRATION OF RFID AND EXCEL-BASED DATABASE

Item	tinf (ms)	Fps	Confidence	Map	ID Tracking
Bottle	145.36	6.58	42.76%	37.3% (mAP@50-95)	11
Bottle	131.7	7.35	81.29%	37.3% (mAP@50-95)	14
Bottle	139.6	6.92	59.07%	37.3% (mAP@50-95)	15
Bottle	120.97	8.03	93.78%	37.3% (mAP@50-95)	18
Bottle	130.9	7.42	78.90%	37.3% (mAP@50-95)	22
Bottle	132.46	7.35	87.49%	37.3% (mAP@50-95)	23
Bottle	127.73	7.57	52.26%	37.3% (mAP@50-95)	26
Bottle	126.48	7.69	65.23%	37.3% (mAP@50-95)	27
Bottle	119.86	8.03	70.94%	37.3% (mAP@50-95)	28
Bottle	122.81	7.91	70.97%	37.3% (mAP@50-95)	30
Bottle	120.61	7.97	62.74%	37.3% (mAP@50-95)	34
Bottle	71.92	13.47	49.68%	37.3% (mAP@50-95)	2
Bottle	71.92	13.47	67.30%	37.3% (mAP@50-95)	3
Bottle	66.66	14.44	45.53%	37.3% (mAP@50-95)	4
Bottle	67.18	14.37	89.95%	37.3% (mAP@50-95)	5
Bottle	64.8	14.91	82.25%	37.3% (mAP@50-95)	6
Bottle	69.96	13.83	81.25%	37.3% (mAP@50-95)	7
Bottle	76.04	12.67	75.36%	37.3% (mAP@50-95)	8
Bottle	75.54	12.78	84.34%	37.3% (mAP@50-95)	10
Bottle	72.33	13.31	90.37%	37.3% (mAP@50-95)	12
Bottle	70.73	13.58	82.88%	37.3% (mAP@50-95)	13
Bottle	69.82	13.81	73.71%	37.3% (mAP@50-95)	14

Based on the test log data, the transparency and validity of the system can be analyzed as follows Measurable Identity and Economic Recording: The system successfully maps each inserted bottle to a specific user identity, in this case a user named *"AHMAD ADI WICAKSONO."* Each detected bottle unit is automatically converted into an economic value ("Price") of 100 points.

Data-Driven Detection Accuracy: System transparency is supported by technical data recorded in the database, where each detected bottle is associated with a varying confidence level, with the highest value reaching 93.78%. This indicates that points are awarded only when the You Only Look Once version 8 nano (YOLOv8n) system is sufficiently confident that the detected object is indeed a bottle. Speed and Performance Analysis: The database records show that the system operates in real time, with fluctuating processing speeds and stable FPS values ranging from 6.58 to 14.91 FPS. This performance ensures that users do not experience significant delays in receiving point confirmation on the liquid crystal display (LCD) display.

D. Circular Economy Impact and Sustainable Community Development

The implementation of the ECO-PAY machine directly encourages changes in community behaviour toward a sustainable lifestyle. Through a reward mechanism controlled by a microcontroller, the waste disposal process is transformed from a burden into a productive activity with economic value.

The waste bin door, which opens only through relay activation after object validation, ensures that only high-quality plastic bottle waste enters the collection container. This process preserves the material purity of the waste for recycling, which represents a core principle of the circular economy transforming waste into valuable new resources, as illustrated in Fig 5.

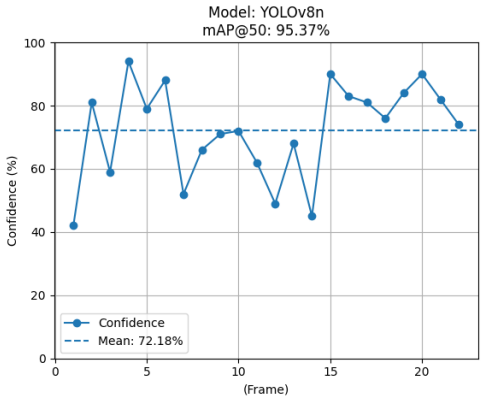


Fig. 5. Analysis of YOLOv8n Accuracy Stability Data

A more in-depth analysis based on accuracy stability data indicates that the system demonstrates high reliability in maintaining the circular economic value chain. Based on the confidence score graph, the You Only Look Once version 8 nano (YOLOv8n) system achieves an average detection accuracy of 72.18% in identifying plastic bottles. Although fluctuations in confidence values occur due to variations in camera angles or lighting conditions when bottles are inserted, the system consistently achieves confidence levels above 80% at many detection points, even reaching a maximum value of 93.78%.

This high level of accuracy is critical to ensuring that economic incentives (points) are awarded only to valid objects, thereby preventing potential losses in the community waste management system caused by misclassification of non-bottle objects.

From a technical perspective, the integration between object detection data and automatic database logging establishes a continuous monitoring system. The log data indicate that the system can handle intensive collection activities within a short time frame while maintaining adequate frame-per-second (FPS) performance, ranging from 6.58 to 14.91 FPS. This performance stability, combined with sequential tracking ID records, enables community administrators to audit collected waste volumes in real time. Consequently, this system supports the development of a sustainable community in which everyone has a transparent record of environmental contributions, ultimately

strengthening public trust in this technology-based circular economy system.

IV. Conclusion

Based on the testing results and discussions conducted on the ECO-PAY system, several key conclusions can be drawn as follows:

The proposed system has been successfully implemented as an integrated solution for plastic bottle waste management by combining You Only Look Once version 8 nano (YOLOv8n) -based object detection and RFID (Radio Frequency Identification) user identification. Experimental testing shows that the You Only Look Once version 8 nano (YOLOv8n) model achieved a maximum confidence score of 93.78% with an average detection accuracy of 72.18% in identifying plastic bottles, enabling the relay-controlled compartment door to activate only for valid recyclable objects. In terms of performance, the system operated stably in real time with a frame rate ranging from 6.58 to 14.91 FPS, which is sufficient to support fast and continuous point transactions in public usage scenarios without significant delays. Furthermore, all transaction data—covering user identity, detected object type, and accumulated reward points—were successfully recorded in a community-based Excel database in a chronological and personalized manner, ensuring transparency and accountability. Overall, these results indicate that the developed system is technically feasible, reliable, and effective in supporting sustainable waste management practices and the implementation of a circular economy model.

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