Design and Implementation of Automatic Waste Segregator

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ABSTRACT

This paper presents the design and implementation of an automated waste segregation system based on Programmable Logic Controller (PLC) technology. The system employs multiple sensors to detect key physical properties—conductivity, magnetic response, and material density—for classifying waste into metals, non-metals, and plastics in real time. A combination of actuators and conveyor mechanisms directs the sorted materials into designated bins with minimal manual intervention. The Q-series PLC serves as the central controller, coordinating sensor inputs and actuator responses, while a Human-Machine Interface (GOT2000) provides real-time monitoring and user interaction. Experimental trials demonstrate reliable classification performance, highlighting the potential of PLC-based control for cost-effective and efficient recycling automation.

Keywords: PLC-based waste segregator, Conductivity-magnetism sensor fusion, Conveyor-pneumatic pusher sorting, GOT2000 HMI visualization, Metal-plastic-non-metal classification

Introduction

Due to the dramatic increase in waste generation as a sector, there has never been a greater need for functional and scalable waste management systems. In addition, the operational costs, accuracy and efficiency of traditional methods of disposables segregation, which have included manual selections and sorting; are also limited. Not only are manual selections time-consuming, frequently mistakes are made in these selections and sorting processes will negatively affect outcomes of the environment and the recycling process. Moreover, by minimizing human inputs; speed, accuracy, and efficiency will be improved via the looking at automation of waste management - more specifically for the segregation operations.

The automated waste segregation system presented in this thesis, relies on various sensors that measure material characteristics such as electrical conductivity, magnetic properties, and material density. Once the system detects a waste material, the segregation system will take the input signal corresponding to the waste material and then sort it into one of three material classifications: metals, nonmetals, and plastics; where the system will direct each material to their respective suitable bin, by guided actuation and conveyor. The uniqueness of this work was to combine conductivity, magnetic and density sensor signals to improve the material classification accuracy using a straightforward and applicable ladder logic simulation to target Programmable Logic Controller (PLC)-based waste segregation. The system will incorporate a Human-Machine Interface (HMI) (in this present thesis the GOT2000) climate control and monitoring in real-time operation. Furthermore, following a thorough cost analysis; it was proposed that the cost of the presented "Automated Waste Segregation Technology", while all costs were considered versus their industrial alternatives, significantly reduced implementation costs segregation lines.

Literature Survey

Automated waste sorting has become an important area of focus in recycling systems in order to create more efficiency and less human involvement in hazardous areas. In the aspect of industrial automation, robots with PLCs have demonstrated viable quality, reliability, and safe reporting and sampling of waste while sorting the waste.[1] In the proposed study by Katkar, the researchers demonstrated a PLC-based system to segregate scrap from industry. The first part of the experiment mapped the materials segregation using sensors and actuators programming. Overall, Katkar's study showed how PLCs could aid in sorting metallic from non-metallic, decrease the required human labour intensity, achieve consistency and accuracy, and provide and provide operational operational efficiencies.[2] In the study led by Siddappaji, the authors selected examined current technologies in waste management, shifting the key focus as technologies moving away from manual sorting and processing towards development of sensors based semi-automated systems.

The paper outlines challenges related to implementation and the benefits of integrating automation into municipal waste management infrastructure.[3] S. P. M extended this concept by introducing a pollution detection mechanism integrated with a waste reporting framework. Their system combines IoT, real-time monitoring, and systematic reporting, supporting both environmental tracking and sustainable disposal practices.[4] Byzov presented a unique perspective by analyzing the social and economic aspects of ecological safety in waste management. They emphasized the importance of risk perception and economic viability when deploying automated systems in public and industrial sectors.[5] Chepa provided a comparative study of different segregation methods, including smart bins, robotic systems, and sensor-based models. Existing waste segregation systems suffer from sensor inaccuracies (e.g., 15% missed metal detection, 8%–12% IR false rates) and limited scalability (10–15 items/min, high expansion costs). The proposed PLC-based system improves accuracy to over 95%, reduces false positives below 5%, and handles up to 30 items/min,

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C. Mohan Raj, N. Pushpalatha, Suresh Kumar Chiluka, P. Rithanya, S. Prasanth, R. K. Pranav and S. Abinithi – Conceptualization, Writing – original draft, review and editing – Conceptualization, Writing – original draft, review and editing

Guarantor: C. Mohan Raj

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offering a precise and scalable solution for industrial use. Their findings reinforce the need for customizable solutions depending on the geographic and economic context. Building upon this body of work, the current study introduces a sensor-integrated, PLC-controlled waste segregation system capable of distinguishing metals, non-metals, and plastics based on properties such as conductivity, magnetism, and density.

Block Diagram

The block diagram of the waste segregator is shown in the Figure 1. This diagram represents the architecture of an automated material sorting system designed to segregate materials such as metals, non-metals, and plastics using sensors, a controller, and a mechanical setup. The process begins with sensors that detect the material type as objects pass along the conveyor. These sensors identify metals, non-metals, or plastics based on their physical or chemical properties, and the detected data is transmitted to the system through digital inputs (DIs). The DIs act as the interface, converting sensor signals into a format that can be processed by the R04 PLC, which serves as the brain of the system. The PLC analyses the input data, determines the type of material, and sends corresponding output commands to the mechanical setup. The Regulated General Industrial Power (RGIP) power supply can be detailed further by specifying its operating voltage (e.g., 230 V AC), inclusion of voltage regulation features, and integration with a UPS backup system to ensure uninterrupted operation and reliability in industrial environments. The digital outputs from the PLC control the two primary components of the mechanical setup: the conveyor and segmentation system. The conveyor is responsible for moving the materials past the sensors and to the segmentation area. The segmentation system has actuators or pushers that utilize the commands by the PLC to sort the materials into different segments. The setup has a HMI (Human-Machine-Interface, GOT2000 model), that provides a visual display for users to monitor the process. Users can utilize the HMI to observe data and materials count in real-time on the HMI, adjust the height of the actuated pusher to stack materials, alter the conveyor speed (in terms of mm/s or materials count speed), turn the conveyor on or off or adjust an infeed vignette if one was present. However, the HMI is limited in its capabilities because there are no alerts that users could receive or any type of manual override. Altogether, the conveyor and segmentation system is a fully efficient and automated material sorting system that provides reliable and accurate segmentation with reduced manual

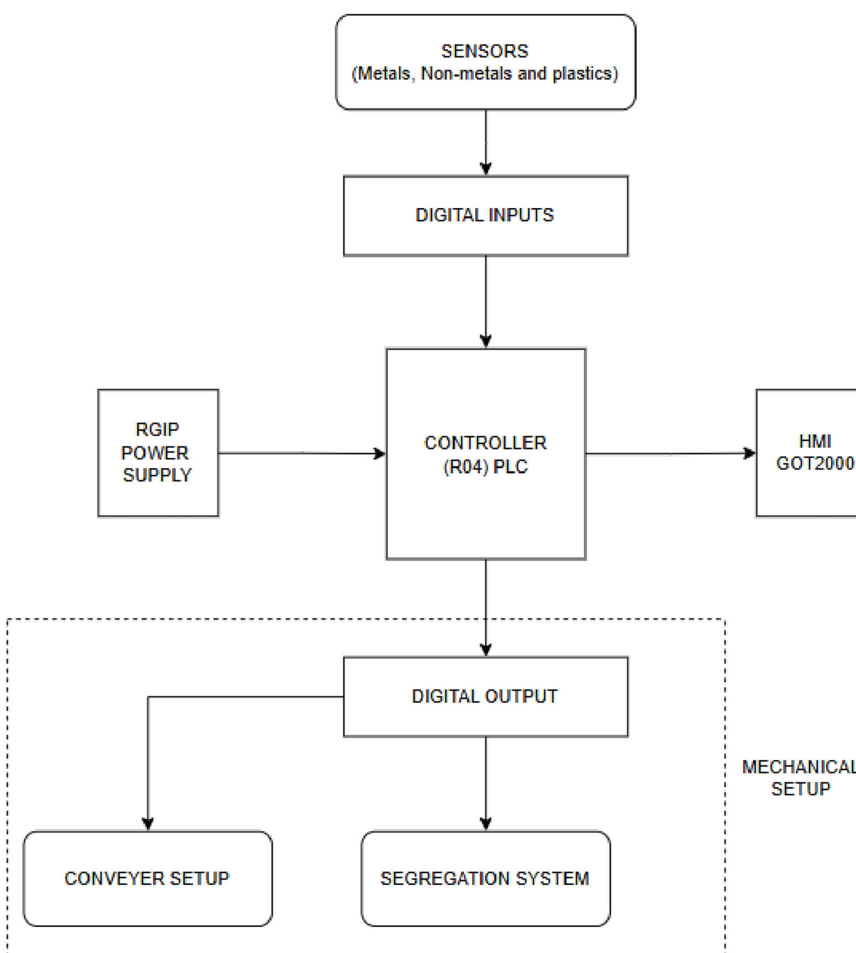

Fig 1 | Block diagram

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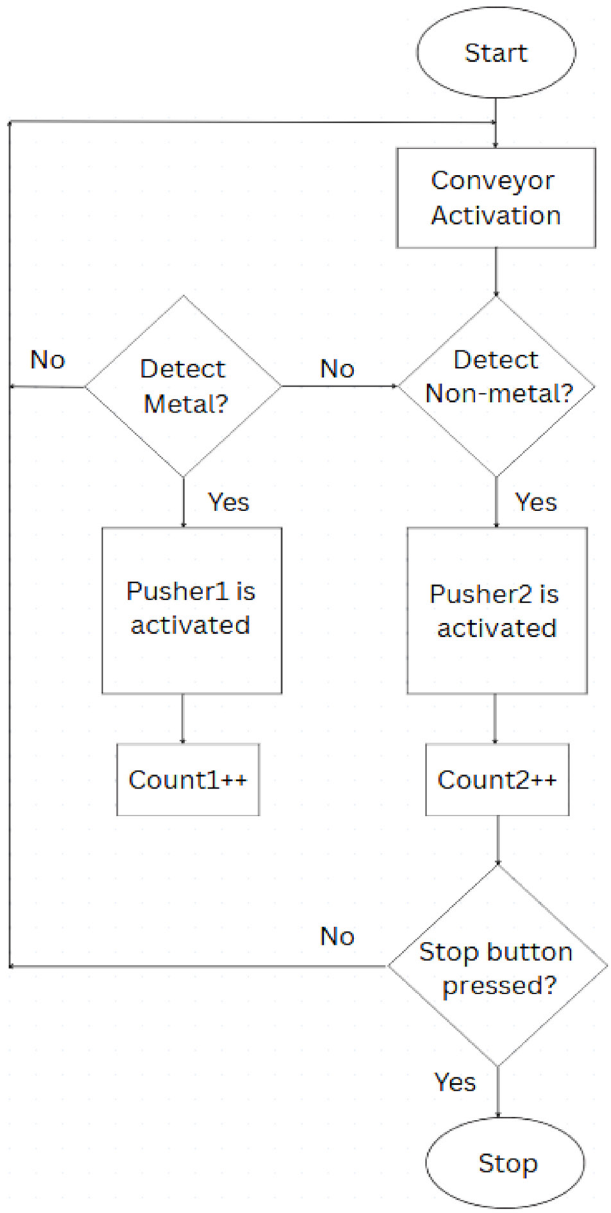

Fig 2 | Flowchart of proposed system

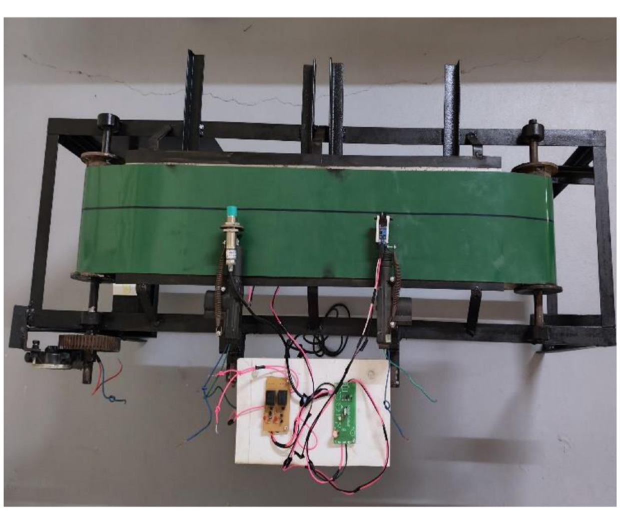

Fig 3 | Idle mode

labour and better overall operational efficiencies in the context of industrial settings.

Workflow

Waste segregator flow chart is shown in Figure 2. This flowchart describes an automated material sorting system that uses a conveyor and pushers to sort a single unique object type into metal, plastic, and wood bins. The waste segregator starts by initializing the DIs and the register fields, which could also be variables, needed to measure materials, as well as update the counters needed to incrementally track counting each new piece. After the waste segregator initializes, it waits for the start button to be pressed. The waste segregator does nothing until the start button is pressed. Once the conveyor motor has been powered on and objects are moving, objects slide through the conveyor system that allows various sensors to detect their material type. When an object is detected as metal, Pusher1 is activated and moves the object into the bin for metal, then the Count1 register value increments by 1. When a plastic object is detected, Pusher2 pushes the object into the bin for plastic, then the count value for Count2 is updated. A third machine component, Pusher3 diverts wooden materials into a wood bin, then the Count3 updates. With the three components, the system sorts by distinctive material category for each new piece of waste. The entire system works continuously verifying the waste stream, sorting waste streams, and counting waste while the stop button is not pressed. At the same time, the system is continuously monitoring the stop button. If it is activated, the conveyor and sorting operations will stop immediately and the process will end. The system provides fast and accurate sorting of materials, tracking how many objects there are in real time for each type of material. The start and stop buttons also provide a level of control back to the users of the system to improve both safety and convenience. This design is suited for automated sorting system operations, in industries that require a material classification and efficient management.

Modes of Working

In our project, the system operates in three distinct modes based on the type of waste detected and system status, ensuring efficient and accurate waste segregation. The three modes are:

- Mode 1 - Idle Mode
- Mode 2 - Metal Detection
- Mode 3 - Non-Metal Detection

Mode 1 – Idle Mode

The Idle Mode is the default state when there is no waste item on the conveyor belt as depicted in the Figure 3. In Idle Mode, the sensors are monitoring for the presence of any object, while the motor is not running or is at a stand by speed to reduce energy consumption. The PLC stays alert, ready to switch to either Metal Detection Mode or Non-Metal Detection Mode as soon as an object is detected by the sensors. This mode ensures that the system is always prepared to respond

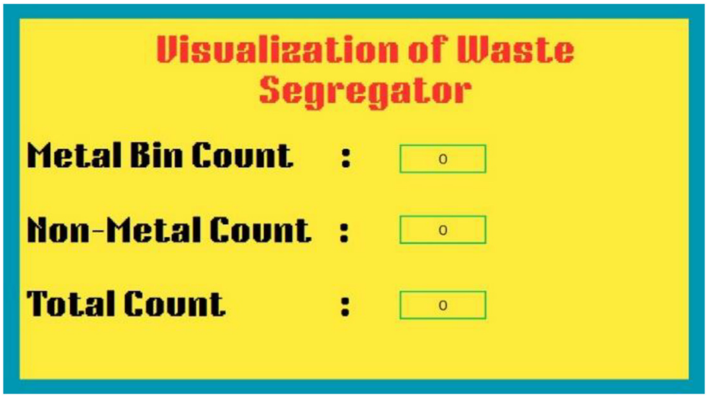

Fig 4 | HMI screen during mode 1

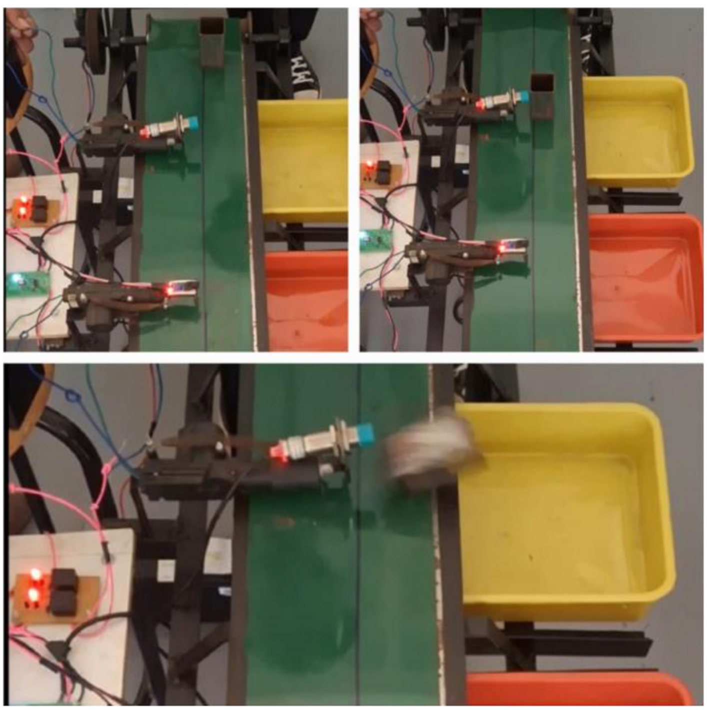

Fig 5 | Metal detection

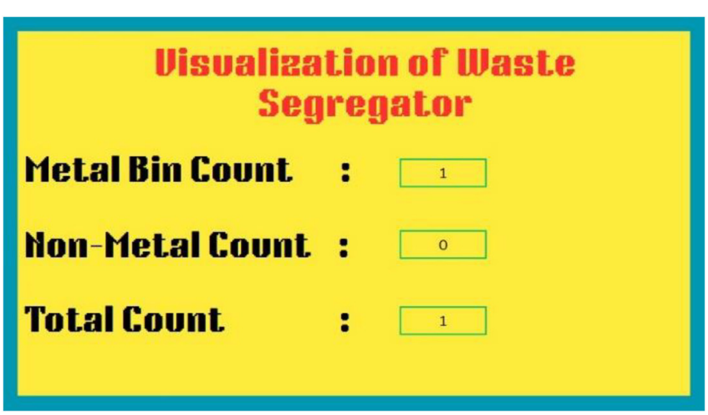

Fig 6 | HMI screen during mode 2

immediately when waste is introduced, maintaining efficiency and responsiveness.

On the HMI screen, real-time counts for metal objects, non-metal objects, and the total number of items processed are displayed. During the Idle Mode, all these counts remain at zero, indicating that no objects have been detected or processed yet as shown in the Figure 4.

Mode 2 – Metal Detection

Metal Detection Mode is activated when the proximity sensor detects a metallic object on the conveyor. Once the metal is identified, the PLC processes the signal and initiates a diversion mechanism to separate the metal from the waste stream as shown in the Figure 5. In this mode, a plunger is employed as the primary actuator, which is precisely controlled by the PLC. The plunger swiftly pushes the detected metal object off the conveyor and into a designated metal bin. This ensures accurate and efficient segregation of metallic waste. After the metal is successfully diverted, the system resets and returns to Idle Mode, ready to detect the next object. This mode enhances the automation and reliability of the segregation process, reducing manual effort and increasing sorting efficiency.

In Metal Detection Mode shown in Figure 5, when a metallic object is detected and successfully diverted, the metal object count on the HMI screen is incremented, reflecting the addition of the newly identified metal item. Now the count of metal bin becomes one and the total count results in the as one as shown in the Figure 6.

The proximity sensor is used to detect the presence of metal objects based on their ability to disrupt the sensor's electromagnetic field. When a metal object is detected, the sensor sends a signal to the PLC, which then activates the appropriate sorting mechanism to segregate the metal waste.

Mode 3 – Non-Metal Detection

Non-Metal Detection Mode is initiated when the IR sensor detects a non-metallic object on the conveyor. Upon detection, the PLC receives the signal and activates the appropriate response to divert the non-metallic waste as shown in the Figure 7. Unlike the metal detection process, this mode may use a separate plunger or guide mechanism to push the object into a different bin designated for non-metal waste.

The conveyor briefly pauses to ensure accurate positioning, allowing the plunger to push the item efficiently. After the object is successfully diverted, the system resumes operation and returns to Idle Mode. This mode plays a crucial role in ensuring effective separation of non-metallic waste materials, contributing to organized sorting and better waste management. In Non-Metal Detection Mode, when a non-metallic object is detected and successfully diverted, the non-metal count displayed on the HMI screen is incremented by one, reflecting the newly identified item. As a result, the non-metal bin count becomes one, and the total object count updates to two, as illustrated in Figure 8.

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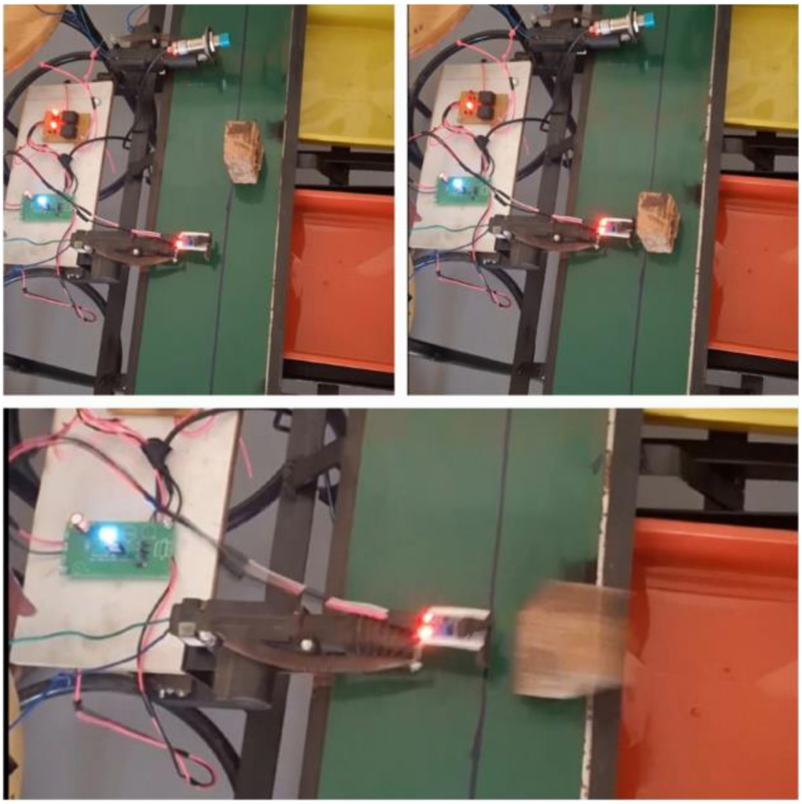

Fig 7 | Non-metal detection

Fig 8 | HMI screen during mode 3

Software Programming

The ladder logic diagram for the waste segregation system is shown in the Figure 9, automates the sorting of materials such as metals, plastics, and wood using a PLC. The input and output details are shown in the Table 1. The process begins when the Start button (X0) is pressed, energizing relay M0, which powers the system and activates the conveyor belt (Y20) to transport materials along the production line. As the materials move, the sensors detect the material type. The Metal Sensor (X2) detects metal objects and triggers Timer T0, which introduces a delay to ensure the metal is correctly positioned for sorting. Once the delay is over, Pusher 1 (Y21) is activated to push the metal material into the designated bin. Similarly, the Plastic Sensor (X3) detects plastic materials, triggering Timer T1, which ensures.

Propsed System Prototype

The results of our waste segregation project, utilizing a PLC module demonstrate a significant improvement in the accuracy and efficiency of waste sorting when compared to conventional methods or less advanced automated systems. Figure 10 illustrates the physical prototype setup, which comprises a Mitsubishi Q-series PLC selected for its high-speed processing, modular expandability, and built-in Ethernet communication, making it well-suited for real-time waste segregation systems that require fast sensor response, future scalability, and reliable data handling compared to basic or less flexible PLC models, a GOT2000 HMI, a conveyor system, pneumatic pushers, and material-detecting sensors including inductive, capacitive, and optical types. During trails, sensor malfunction leading to false negatives (failing to detect metal objects) due to low signal strength or sensor misalignment. The system can be enhanced by integrating safety features like an emergency stop button, overload protection circuits in the RGIP supply the integration of sensors for material detection ensures reliable classification based on properties like conductivity, density, and optical characteristics. Unlike manual sorting, which is prone to human error and labor-intensive processes, our system ensures consistent operation, minimizes errors, and reduces dependency on human intervention.

Reliable material classification through sensor operation (conductivity, magnetism, density detection, etc.) involves a calibrated measurement of certain properties that can be made accurate by use of reference materials – the reference material quantifies the conductivity of the fluid being sampled, and specifies a conductivity range for successful/unsuccessful complete extraction of the desired object. To verify its reliability, the sensor is connected to a PLC. It will enable an adjustment and monitoring of the system in real time, without human intervention. Especially as a solid waste recycling system may be based on a variety of waste streams, once the sensor is verified for the particular waste stream it will transpire a material classification without intervention or supervision, making this system suitable for a range of applications, from industrial waste management to urban recycling centers and the likes.

Comparison (Table 2)

A summary of the future comparison is presented in Table 1.

Results

Each independent run consisted of 15 mixed items (metals, plastics, and wood), resulting in a total of 45 items across the 3 runs (Table 3). The system achieved an overall accuracy of 93.3% with confidence intervals at 95% between 82.1% and 97.7%. The FPR remained less than 5% with the average being 3.3% for each run. The throughput was an average of 30 items/min and was consistent with the design target of 30 items/min.

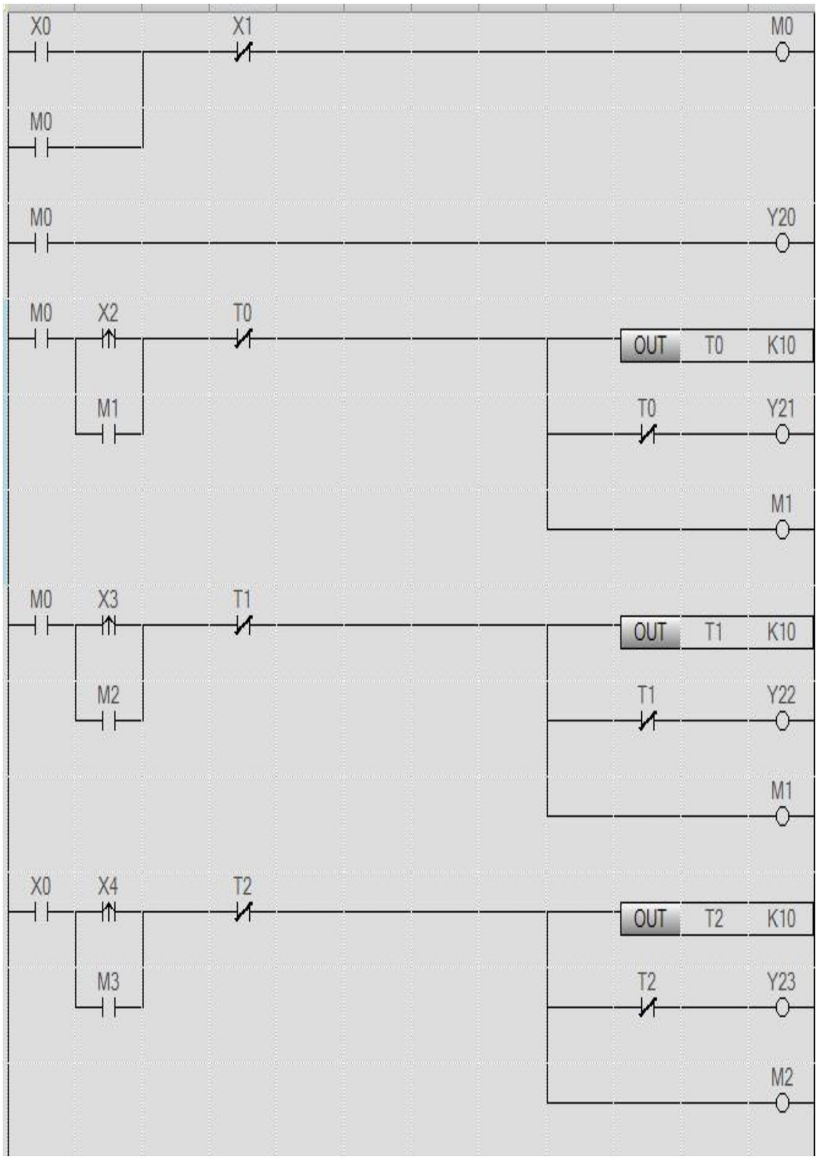

Fig 9 | Ladder logic

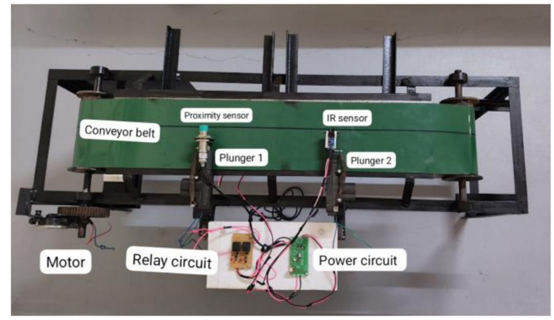

Fig 10 | Prototype of proposed system

Table 2 | Features comparison

Feature	Existing System	Proposed System (Using Mitsubishi Q03UDE PLC)
Controller	No centralized controller or manual human decision-making	Mitsubishi Q03UDE PLC (and R04 PLC
Automation Level	Manual sorting or semi-automated with minimal sensor use	Fully automated with real-time control and decision-making
Material Detection	Automated identification of metals, non-metals, and plastics	Relies on human judgment, often error-prone
Conveyor System	Motor-powered, PLC-controlled for precise movement	May be manually operated or simple motor-based without feedback
Power Supply	Standard power supply	RGIP power supply ensures uninterrupted performance
Initial Investment	Lower initial cost	Higher upfront cost for PLC and sensors
Efficiency and ROI	Limited by human intervention and working hours	High efficiency, 24/7 operation (30 items/min, 14,400 items/day, with 36 kWh/day)
Accuracy Rate	75%–90%	92%–97%
Processing Speed	10–20 items/min	20–30 items/min

Table 1 | Input and output details

S. No	Name of the I/O	PLC DI/DO Address
1.	Start PB	X0
2.	Stop PB	X1
3.	Metal Sensor	X2
4.	Plastic Sensor	X3
5.	Wood Sensor	X4
6.	Conveyor Setup	Y20
7.	Pusher1	Y21
8.	Pusher2	Y22
9.	Pusher3	Y23

Future Scope

Future upgrades involve scaling the system to handle high-volume waste and adding sensors to handle different materials such as glass and organics. By using sensor fusion, filtering of data, and redundancy the system's accuracy can be improved with real-time metrics to quantify the environmental impact. Increasing reliability and expandability, will come from features jam detection and possible addition of IoT and AI technologies. The upgrades will improve the efficiency, intelligence, and feasibility of the system for use in an industrial scale.

Conclusion

This project, the "Design and Implementation of Automatic Waste Segregator", has done well to demonstrate our ability to shift from theoretical learning to practical application. It offered us a greater appreciation of project management, assembly of components, machining and testing, which has shaped our practicality; an essential skill needed to be successful in our careers. We transcended time and resource limitations that conventional constraints create in developing a system that works in accordance with our

Table 3 | Test and validation

Run	Items Tested	Accuracy (%)	95% CI (low–high)	Macro False Positive Rate (FPR) (%)	Throughput (items/min)
Run 1	15	93.3	74.6–99.3	3.1	30.0
Run 2	15	93.3	74.6–99.3	3.4	29.4
Run 3	15	93.3	74.6–99.3	3.4	30.6
All	45	93.3	82.1–97.7	3.3	30.0

goal. The waste segregator is evidence of our success to overcome our limitations to work around less than desired facilities. It is important to note that automation in modern day industry can lessen the need for manual labour and increase productivity. In closing the "Design and Implementation of Automatic Waste Segregator" leaves evidence of our ability to overcome limitations while converting ideas into products.

References

1 Katkar VA, Pawar SS, Katke A. Industry scrap segregation using PLC. In: Proceedings of the 5th international conference on computing, communication, control and automation (ICCUBEA), Pune, India; 2019. p. 1–4. https://doi.org/10.1109/ICCUBEA47591.2019.9128464

2 Chepa S, Singh S, Dutt H, Sharma A, Naik S, Mahajan H. A comprehensive study of distinctive methods of waste segregation and management. In: International sustainability and resilience conference: climate change, Sakheer, Bahrain; 2021. p. 440–4. https://doi.org/10.1109/IEEECONF53624.2021.9668020

3 Byzov AP, Efremov SV, Gomazov FA. Social and economic aspects of acceptable risk of ensuring ecological safety at management of municipal waste. In: 2018 IEEE international conference "management of municipal waste as an important factor of sustainable urban development" (WASTE), St. Petersburg, Russia; 2018. p. 60–2. https://doi.org/10.1109/WASTE.2018.8554106

4 Samuel Prabakaran M, Sophia S, Sophas Samuel S. Optimizing waste management: integrated pollution detection and systematic reporting for sustainable disposal. In: 2024 2nd international conference on networking and communications (ICNWC), Chennai, India; 2024. p. 1–7. https://doi.org/10.1109/ICNWC60771.2024.10537396

5 Siddappaji, Sujatha K, Radha RC. Technologies for segregation and management of solid waste: a review. In: 2016 international conference on emerging trends in engineering, technology and science (ICETETS), Pudukkottai, India; 2016. p. 1–4. https://doi.org/10.1109/ICETETS.2016.7603046

6 Sri Sangeetha R, Pushpalatha N, Gururaj P, Dharmaselva R, Hemalatha N, Gunapriya D. Twofold base IoT-based intelligent power quality monitoring system by considering social stewardship. In: Advances in intelligent systems and technologies; 2023. p. 073–7. https://doi.org/10.53759/aist/978-9914-9946-4-3_12

7 Sharma KD, Prajapati RK, Srivastava S, Fore V, Amrish A. Design and fabrication of an automatic waste segregation and monitoring system. Curr World Environ. 2024;19(3). https://doi.org/10.12944/CWE.19.3.15

8 Babu WR, Pusphalatha N, Raj Thilak K, Janani K, Catherine L, Sharma V. Space-based GPS solar tracking system. In: Advances in engineering research; 2024. p. 371–82. https://doi.org/10.2991/978-94-6463-529-4_33

9 Pushpalatha N, Akshaya MI, Jaswanthi Sai J, Gowri Shankar G, Mohamad Mubarak A, Gowtham M. A smart approach towards sustainable development through an IoT-powered recycling bin. In: 2024 International conference on recent innovation in smart and sustainable technology (ICRISST), Bengaluru, India; 2024. p. 1–4. https://doi.org/10.1109/ICRISST59181.2024.10921876

10 Hemananth B, Sagaya Pushpam AJ, Venkateswarlu G, Balaganesan SM, Poonguzhali PK, Gokul S. Modular controller based intelligent system for smart autocleaning and effective usage of utensils. In: 2023 international conference on intelligent data communication technologies and Internet of Things (IDCIoT), Bengaluru, India; 2023. p. 997–1000. https://doi.org/10.1109/IDCIoT56793.2023.10053549

11 Shanmugasundaram R, Josha Daniel S, Yadav PD, Patil DT, Shinde Y, Raj CM. Design and control of PV based isolated power supply using iQF controller for agricultural. In: 2024 international conference on expert clouds and applications (ICOECA), Bengaluru, India; 2024. p. 371–4. https://doi.org/10.1109/ICOECA62351.2024.00072

12 Smith YR. Eddy current separation for recovery of non-ferrous metals from mixed waste. Recycl Technol J. 2019;5(2)88–95. https://doi.org/10.1016/j.recytec.2019.05.002

13 Kamarudin NH, Rahim AAA, Abdullah NE, Halim ISA, Hassan SLM. Development of automatic waste segregator with monitoring system. In: 2019 4th international conference on information technology, information systems and electrical engineering (ICITISEE), Yogyakarta, Indonesia; 2019. p. 190–5. https://doi.org/10.1109/ICITISEE48480.2019.9003813

14 Singh CP, Manisha M, Hsiung P-A, Malhotra S. Automatic waste segregator as an integral part of smart bin for waste management system in a Smart City. In: 2019 5th international conference on computing, communication, control and automation (ICCUBEA), Pune, India, 2019. p. 1–5. https://doi.org/10.1109/ICCUBEA47591.2019.9129508

15 Deeksha More EK, Divya S, Kalyani G, Gowthami R. Automatic waste segregator bin using robotic arm. In: 2018 3rd IEEE international conference on recent trends in electronics, information & communication technology (RTEICT), Bangalore, India; 2018. p. 1555–8. https://doi.org/10.1109/RTEICT42901.2018.9012120