Advances in Machinery, Materials Science and Engineering Application IX
M. Chen et al. (Eds.)

doi:10.3233/ATDE230531

Material Recovery Facility (MRF) Sorting System Using Programmable Logic Controller (PLC)

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Abstract. The study was conducted to assess whether the PLC could operate the proposed prototype and segregate waste materials classified as metal (tin can), glass (glass jar), or plastic (plastic bottle). Electrical, electronic, and mechanical components were determined based on the requirements and compatibility of the system. The designed and programmed PLC ladder diagram was used to operate the system and then evaluated in terms of its functionality, reliability, process rate, and accuracy. After several trials, the Material Recovery Facility Sorting System using PLC was developed. It was found that all components were functional and effectively performed their respective tasks. The proposed system is functional, reliable, and accurate enough to sort waste materials according to their type (glass, metal, plastic) with a processing time of 21 seconds for tin cans, 22.46 seconds for a glass jar, 18.48 seconds for plastic bottles, and 18.51 minutes for segregating 20 kilograms of waste materials. Thus, it has the potential to reduce the unsafe and labor-intensive system in the current manual sorting process at the Material Recovery Facility situated in Brgy. Masipag, Koronadal City.

Keywords. Material recovery facility, PLC, sorting system, waste materials, solid waste segregation

1. Introduction

Solid waste processing, sorting, and recycling are significant community challenges, and improper treatment damages human safety and the environment. Solid waste capacity and categories are growing fast due to urbanization, economic growth, industry, and population.

The Philippines has over 100 million people and generates 0.5 kg and 0.3 kg of solid trash daily in urban and rural areas. An estimated 50,000 MT are created per day, and 35,000 are collected [1]. Municipal solid waste comes from homes, businesses, institutions, and industries. Residential trash accounts for 56.7% of MSW, whereas commercial sources, such as businesses and public or private markets, contribute

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27.1%, or two-thirds in some locations. Institutional MSW accounts for 12.1%, whereas industrial or manufacturing trash accounts for 4.1% [2].

Barangay Sta. Cruz, Koronadal City, South Cotabato, has 3,241 households due to rapid housing subdivision development and a significant immigrant population. Its Barangay Ecological Solid Waste Management Committee (BESWMC) has implemented the "Community Solid Waste Management Program" to promote a clean environment among its constituents through solid waste segregation and collection. Every weekday, the Barangay collects garbage by Kerbside, using two dump trucks, a top-down tricycle, and a stationary trike. The garbage collector will only collect correctly separated waste into biodegradable and non-biodegradable. All residences must have biodegradable and non-biodegradable waste garbage receptacles. Biodegradable garbage is shredded into fertilizer by workers in Brgy. Paraiso landfills in Koronadal City. The Material Recovery Facility in Masipag, Koronadal City, manually sorts non-biodegradable garbage. Metal (tin cans), glass, and plastic garbage are the most prevalent materials for segregation. Mobile buyers recycle these wastes and use them for their new brick project, which uses non-biodegradable waste pulverization. Segregating these items is tedious and time-consuming, risking workers' health and hygiene. Every laborer segregates 20 kilograms daily and pays 6,000 pesos monthly by the Barangay.

Sorting has existed for a long time due to industry challenges and technological improvements [3]. Two issues define every sorting methodology: the form of the criterion aggregation model used for sorting and the methodology used to define model parameters. A few studies used automatic, manual, and online sorting. Some researchers proposed a sorting system using a double-acting pneumatic cylinder to push products to their conveyor belt boxes automatically. Several studies proposed automatic sorting methods to improve material sorting efficiency, energy conservation, and quality productivity.

Furthermore, different types of sorting processes were suggested by Mohid Shadman Rahid Ali, et.al [4]; Bonkole Oladapo, et.al [5]; Li and Yaojie; Timothy , et.al [6] ; Tao and Voronim [7] for various kinds of industrial application. Ali et al. [4] and Oladopo et al. [5] designed and developed an automatic sorting object using proximity, capacitive, and inductive sensors. It can separate non-ferrous metal objects and move them automatically to the basket using motors controlled by the Programmable Logic Controller (PLC) with sensors to detect object values. However, Tao, Timothy, and Li designed a new detection and sorting system control strategy. The study used machine vision, a 3D mechatronic sorting system model, image detection, and recognition algorithms to design and build a color sensor-based optical sorting machine [5] [7] [8].

The main emphasis of this study is the electrical, electronic, and mechanical components, system design, PLC programming, prototype functioning, process rate, dependability, and accuracy. The study would help the community eliminate public dependence and ensure recycling; reduce the health and safety risks of barangay workers, which significantly impair the waste sorting process with lower labor costs, fewer errors, faster processing rates, and less working time; and establish links and network marketing outlets for recyclability.

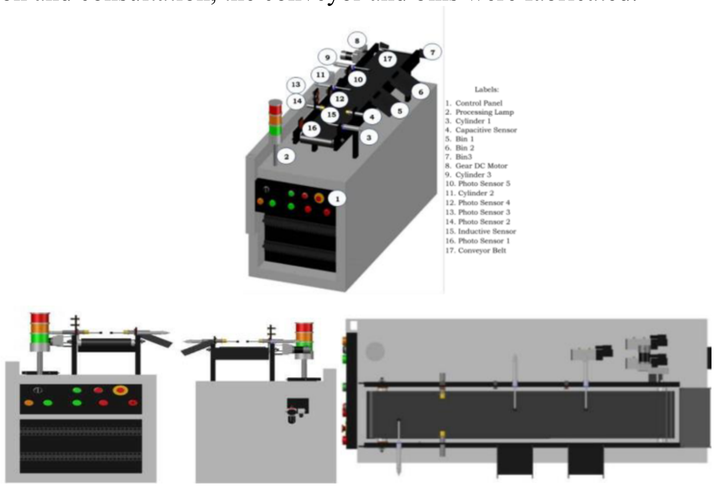
Thus, the Material Recovery Facility Sorting System using Programmable Logic Controller may replace manual sorting of non-biodegradable garbage to save time, decrease errors, and boost production. This system automatically separates metal, glass, and plastic non-biodegradable garbage based on manual segregation.

2. Methodology

The prototype Material Recovery Facility (MRF) Sorting System undergoes four phases: research design planning and fabrication, project development, commissioning and PLC programming, and testing and evaluation.

2.1. Research Design

In this phase, the prototype underwent a series of procedures that started with the project layout (figure 1) using AUTOCAD software for designing specifications and the proper position of components. The development of the prototype also includes the specifications of electrical, electronic, and mechanical components for the system used and their availability in the market through canvassing and purchasing. Through collaboration and consultation, the conveyor and bins were fabricated.



a. Front View; b. Back View; c. Top View

Figure 1. Project Layout of Prototype Material Recovery Facility Sorting System.

2.2. Project Development

Construction of the prototype and wiring of electrical and electronic components occur in this step. The prototype included mechanical assembly, sensor location, and component placement. The prototype's base was a 2.3ft x 1.5ft x 2.6ft scrap stainless table model, while the conveyor and bins were cee-purlin bars and aluminum bars. The conveyor was 4 inches wide and 35 inches long, and the bins were 19 cm x 10 cm x 4.5 cm. The technician mounted a gear DC motor with a 3 cm ball bearing to the conveyor belt to propel the conveyor forward motion. The conveyor belt was 90 cm long and 9.5 cm broad. The sensors were positioned on angle bars to provide stability. The photoelectric sensors were 0.5 cm above the conveyor belt and 13 cm from the reflector. To detect waste material, the authors installed the capacitive sensor 6 cm above the conveyor and the inductive sensor 2.5 cm above the conveyor. The 12 cm-stroke cylinders were then activated and pushed the object to the bin corresponding to its material type. The control panel used pilot lamps and push buttons to control and monitor the system. Festo FluidSim and Electronic Workbench designed and simulated the electro-pneumatic circuit diagram (figure 2) and motor control circuit (figure 3). Cylinders 1 and 2 have throttle valves to regulate piston speed. Cylinder 3 extended its piston as a buffer. A 24VDC gear DC motor powered the conveyor belt at 0.2 amps. A relay should be connected to the motor to activate the 24VDC transformer for a specific voltage and current.

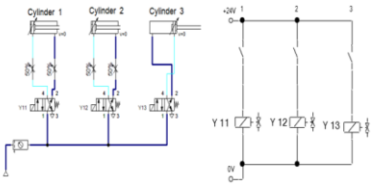


Figure 2. Electro-pneumatics Circuit.

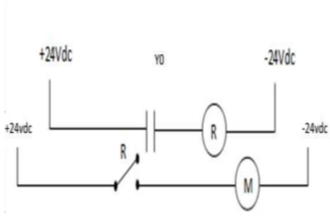


Figure 3. Motor Control Circuit.

2.3. Commissioning and PLC Programming

After wire installation, the authors tested the components and connections to ensure proper wiring, no short circuits, a precise 24VDC supply, and correct inputs and outputs. Activating the double-acting cylinder and solenoid valve, checking the valve for leaks, supplying a 24VDC gear DC motor and relay to the conveyor belt, then turning on the motor, checking for smooth and continuous motion of the belt, and input/output configuration was also done in this phase. Then, the authors commissioned, troubleshoot, programmed the PLC ladder diagram, and ran the prototype. If components failed, it was replaced and wired. The authors used the FX1S CPU Mitsubishi PLC, USB Serial, and GX working applications for programming. The output flowchart (figure 4) determines the system's operation and PLC ladder program operational sequence.

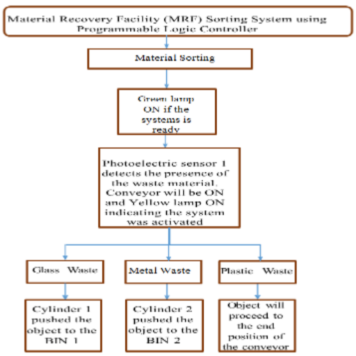


Figure 4. Flowchart of the Output.

2.4. Testing and Evaluation

The prototype was put through a series of tests to assess its functionality, reliability, and accuracy. Computer software or hardware capabilities were employed to test machine functionality. Each prototype component was tested during operation to ensure it performed its task. Reliability was measured by comparing actual and expected production. Thirty waste materials were tested in three trials: glass bottles, tin cans, and plastic bottles. However, accuracy was the percentage of waste segregated over time. For system reliability testing, the number of materials sorted in bins over those entering the system. The mean formula calculated the average sorting time for tin cans, glass, and plastic. The proportion formula was used to analyze the change in error proportions before and after overhauling.

3. Results and Discussion

The prototype output of this Material Recovery Facility Sorting System using PLC was tested for functionality, reliability, process rate, and accuracy.

3.1. Functionality

The electrical, electronic, and mechanical components were all functional and performed their respective tasks effectively. The output flowchart (figure 4) showed that its operating sequence as an observer was efficient in all indicators. Actuators, lamp indications, sensors, and switches worked properly. It proves that the PLC program efficiently sorted waste materials.

The prototype material recovery facility sorting system functionality test revealed issues and errors. Table 1 shows that the cylinder air supply was inconsistent from 30 to 60 minutes into the operation, capacitive and inductive sensors could not detect the material, and the conveyor belt loosened. However, this inaccuracy was adjusted, and trials were done to compare errors before and after overhauling. The maximum operation and testing time was two hours.

Table 1. Prototype MRF's Operation and Testing Time

Components	**Time (minutes)**										
	5	10	15	20	30	45	60	75	90	105	120
PLC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Conveyor	✓	✓	✓	✓	✓	✓	x	✓	✓	✓	✓
Cylinders	✓	✓	✓	✓	x	✓	✓	✓	✓	✓	✓
Sensors	✓	✓	✓	✓	✓	x	x	✓	✓	✓	✓
Switches	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Indicator Lamps	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Legend: ✓ = Good Condition; x= Trouble/ Error

3.2. Reliability

Three trial groups were formed in this phase, as shown in figures 5 and 6. Each trial of Group 1 and Group 2 has 90 pieces of waste (glass, metal, plastic), while Group 3 contains 100 pieces of clean and muddy waste.

Group 1 and Group 2 had high-reliability percentages of above 95% and 92%, respectively, indicating that the prototype MRF was accurate and consistent in sorting waste materials (glass, metal, plastic) in a series of trials. The segregation of Group 2 garbage, especially glass-plastic mixtures, was inconsistent. The sensors may have made errors since glass and plastic were practically transparent.

In figure 6, another test assessed the prototype's reliability. The reliability of the system is between 80% and 90.33%. The MRF prototype could sort garbage by category but needed consistency. The photo, inductive, and capacitive sensors had trouble sensing muddy waste.

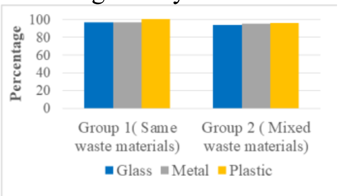


Figure 5. Reliability Results of testing MRF Sorting System prototype in sorting Waste Materials.

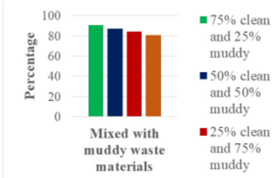


Figure 6. Reliability Results of testing MRF Sorting System prototype in sorting Muddy Waste Materials.

3.3. Process Rate

Process rate testing determined how rapidly the prototype could sort waste materials, whose findings are shown in figures 7 and 8. Figure 7 illustrates the prototype's sorting time and rate for a specified kg of garbage. This study employed barangay segregator data for comparison. The average 2-hour garbage sorting weight is 20 kilos. According to the data, sorting 5 kg of garbage takes 0.029 kg/s, and 10 kg takes 0.022 kg/s. Segregating 15 and 20 kg takes 0.026 kg/s and 0.018 kg/s, respectively. The prototype MRF Sorting System separated 20 kg of garbage in 18.51 minutes. The results reveal that the prototype MRF sorting machine sorts glass, metal, and plastic garbage faster than manual segregation. Also, figure 8 shows how long the prototype takes to sort ten pieces of each waste material. Ten tests were done on each waste material to calculate the average process time and rate. Sorting waste takes 21 seconds for metal, 22.46 for glass, and 18.48 for plastic. The prototype MRF Sorting System can sort 28 metals, 27 glass, and 32 plastic components in a minute.

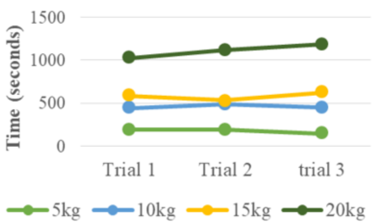


Figure 7. Process Rate and Accuracy of the MRF Sorting System Prototype According to the Weight of Waste Materials.

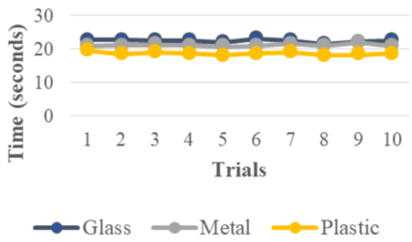


Figure 8. Process Rate and Accuracy of the MRF Sorting System Prototype per piece of waste materials.

4. Conclusion

A prototype Material Recovery Facility Sorting System employing Programmable Logic Controller was designed and developed in this study. The authors identified a functional prototype's electrical, electronic, and mechanical components. The ladder diagram PLC programming has been modified by the authors multiple times to improve reliability and accuracy.

Limitations include testing failure rates due to the limited sensitivity of inductive and capacitive proximity sensors. The prototype cannot correctly segregate waste materials in the specified bins due to the conveyor belt's unsteady motion and the irregular compressed air supply of pneumatic cylinders. Before the operation, the conveyor ball bearing must be checked for lock, and the air service regulator must be set to 8 bars. In the future, it is recommended to use sensors with high sensitivity ratings to produce more exact material, a pressure regulating valve to maintain a consistent supply of compressed air, and a rubber fabric conveyor belt for more stable movement. Additional photoelectric or through-beam sensors can be put in the bins to monitor waste sorting and integrate other processes like compacting, pressing, and handling.

Nevertheless, the MRF Sorting system prototype is functional, reliable, and accurate enough to sort waste by kind (glass, metal, plastic). Thus, it can reduce the unsafe and time-consuming human sorting procedure at the Material Recovery Facility in Brgy. Masipag, Koronadal City, can sort 20 kilograms of non-biodegradable garbage in 18.51 minutes.

Acknowledgment

The authors would like to thank everyone, Mindanao State University-Iligan Institute of Technology, and the University of Southeastern Philippines for their resources, assistance, and guidance during this publication.

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