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Development and Analysis on the PLC Based Sorting System for Recycle Purpose

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ABSTRACT

In the world with frequent of trash-production and wastes that need to be disposed of, it usually takes a long time for these waste products to be recycled naturally. Some of the waste can affect the environment if it is not properly recycled, for example, plastic, metal, and glass. The purpose of this project is to develop an PLC based system in sorting different type of items to be recycled, such as glass, plastic, and metal can. This project involved programming of programmable logic controllers for a sorting process for objects to be recycled. The sensors were used to detect the material or object's type, and this data was used as an input for the system to automatically separate them into three different categories based on the material. Pneumatic cylinder system was used as a pushing mechanism during sorting process. The probability of the constructed prototype in detecting type of material was analysed by testing it with seven objects: a plastic bottle, a plastic bag, a plastic case, a glass bottle, an aluminium can, a metal box, and a metal rod. The findings show that transparency, material type, and material strength significantly impact the results. A high probability in material detection primarily because of the hardness of the materials, facilitating easier differentiation. However, the detection of transparent materials posed challenges, and metal materials were consistently detected in nearly all tests. From the analysis, it is concluded that the current prototype system is still unable to provide high percentage of reliability to detect the materials of the selected object. Increasing the ability to detect the object type is necessary to ensure the success of developing this prototype for PLC based sorting system for recycle purpose. It is envisaged that this system can fasten the sorting process in the future. Besides, with automation application in such industry, there will be a reduced requirement for human labour for the repetitive tasks.

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1. Introduction

The United Nation (UN) establishes the Sustainable Development Goals (SDG) with 17 objectives to tackle global issues such as poverty, inequality and environmental degradation. According to International human rights law and SDGs, the right to healthcare is a fundamental element as it is directly linked to human well-being [1]. In the SDG Goal 12, it involves responsibility in consumption, production, and efficient management of resources, where the management of reducing and disposing waste, encouraging recycling, and reusing waste are equally important [2]. The World Bank of South Asia reports that it is forecasted that by the year 2030, there will be 466 million tons of garbage produced by humans, and by the year 2050, it will increase to 661 million tons [3].

The escalating issue in lacking waste management poses severe threat to our environment, which clearly shows the importance of recycling practices. Planet of Earth facing terrible consequences due to excessive waste generation, such as landfills burgeon, ocean lives choke with plastic, and damages to ecosystem. Due to that, recycling emerges as a crucial solution to these problems, to mitigate the impact of discarded materials. This is necessary to reduce the demand for raw resources, reduce the release of harmful pollutants into the air, soil, and water, and lessening the strain on our ecosystems. Without any doubt, recycling is important in preserving the environment for future generations and strive towards a sustainable and responsible approach to waste management [4,5]. Solid waste management may also prevent the environment from being contaminated or harmed by climate change because of untreated solid waste. This is in addition to the fact that it can prevent pollution of the environment. In addition to this, it has the capability of preventing pollution of water, soil erosion, and air, as well as collecting and managing waste of recycled materials in a way that is both efficient and effective [6].

On the other hand, the SDG's Goal 9, which is Industry, Innovation, and Infrastructure, is important for technological progress to solve environmental challenges and to facilitate sustainable development. This goals also promotes the technological development, research, and innovation that ensuring improvement in services, productivity, technology, and well-being. Modern world is where almost everything can be controlled and operated automatically. The Malaysia Government launched National Fourth Industrial Revolution Policy. Industrial automation and Industry 4.0 are revolutionizing the way companies manufacture, improve and distribute their products with technology that allows for the connection, control and monitoring of production systems or processes in real time. These terms are employed in diverse areas including manufacturing, transportation, and utilities term of "unattended automation" where all tasks are automated. An intelligent and autonomous system is achievable and pursued by most industry player to reduce human labor, increase precision and efficiency in process, enabled effectiveness, and modernized public services [7,8].

Based on literature review, past researchers introduced several studies for the automation applied in the industry. A prototype of automatic conveyor system using programmable logic controllers (PLC) for educational purposes was built and published. This prototype is owned by the university and students can design PLC programs based on what they have learned in class. The prototype of the automatic conveyor system can improve students' interest and understanding of the industrial automation process [9]. A paper presents a study to replace the manual ineffective counting system in industry with a user interface system with a counting mechanism. The main idea of the project is to automate the counting bags with the help of sensors and PLC, and finally, the processed data will be read by SCADA and displayed on the screen. However, more improvements should be made in the proposed SCADA to enable communication between several different machines/systems with high accuracy [10]. A system was developed to sort according to the object's dimensions (height, length, etc.), colors, weight, vision (image processing), and material of an object. The low-cost automation system uses PLC for automation, conveyors to transport the objects, laser sensors used to sense the height of the objects, and pneumatic as a pushing mechanism to sort the objects. However, to sort more than one object in one cycle, more alteration is needed in the hardware and software of the system [11]. A packaging process that remotely controlled and monitored using mobile application was published. A conveyor belt moves the products to a destined place for packaging. The proposed system is proven to make the packing processes faster an improve safety, where the user can easily control the machine without direct touch [12]. A study designed bins with weight sensors, where the system will detect waste weight and calculate the carbon footprint of it. The data will be displayed in a web application, where is expected to motivate people to reduce carbon footprint while separate waste for recycle purpose [13].

Automation in the industrial workplace provides the advantage of improving productivity and quality while reducing errors and waste, increasing safety, and adding flexibility to the manufacturing process. In the automation and control industry, it is crucial for the systems to be able to detect objects' type, detect the presence of an object passing by on a conveyor, calculate the appropriate timing for closure of a door, or other functions. Therefore, the analysis on the success probability in detection technology is important for the design and manufacturing of automation equipment. Technology that involves object type recognition, presence detection, or timing calculations, contributes significantly to the overall efficiency and functionality of automation industries. Focusing on identifying process for different products or distinguishing between items for sorting purposes, precise object recognition is pivotal for streamlined automation processes.

2. Methodology

2.1 Project Framework

Figure 1 shows the flowchart of the PLC programming was constructed to summarize the system function, which was programmed to sort the materials for recycling purpose. Meanwhile, Figure 2 illustrates the whole system conveyor drawing. At the front of the conveyor, three sensors were mounted to give information to the conveyor regarding the type of material for the object placed at the front of the conveyor. If the input signal shows that the object was made of metal, the object will be pushed to box 1. If the input signal shows that the object was made of plastic, the object will be pushed to box 2. If the input signal shows that the object was made of glass, the object will be pushed to box 3. If the materials type is not detected, the object will be pushed to box 4 and be considered as general waste.

Figure 3 illustrates side view of the project, where the installed location of sensors and cylinders were visible. The sensors were connected to the DC power supply and the output are connected as the input of the PLC Omron CP2E-N. The connections that exist between the PLC and the DC power source are capture as shown in Figure 4. The sensors and the pneumatic cylinder are supplied from the direct current power supply in order to function properly. In the meanwhile, the sensor output signal wire is connected to the input side of the PLC. A link is established between the output of the PLC and the pneumatic cylinder.

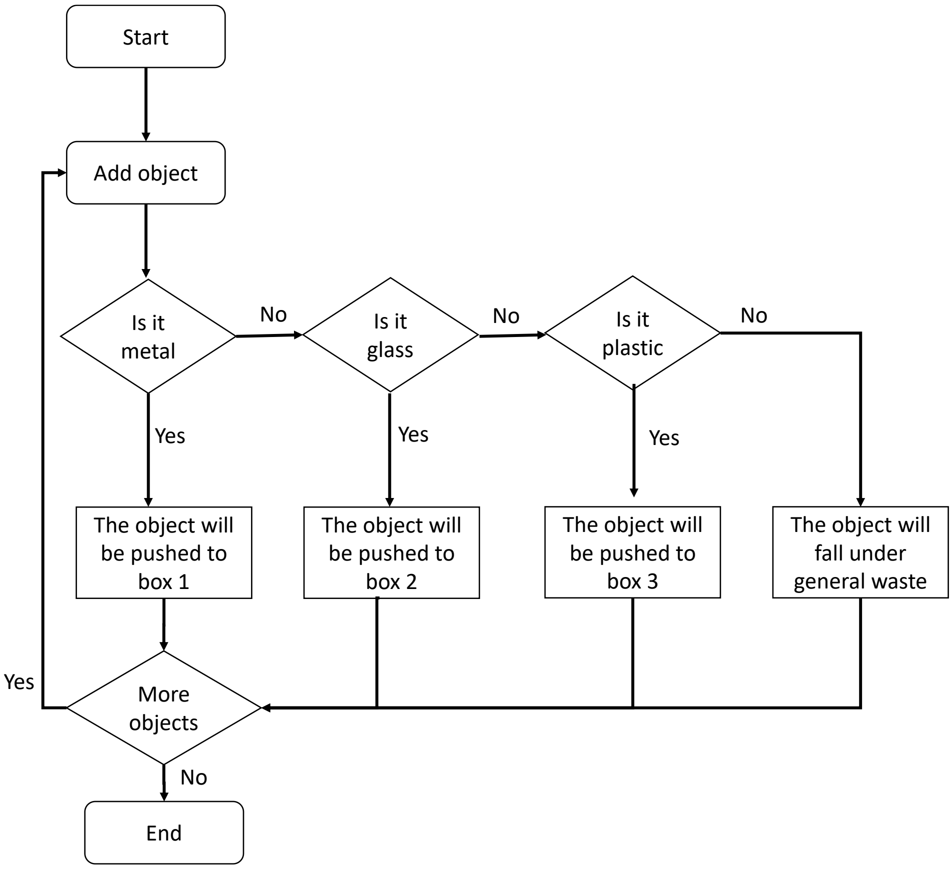

Fig. 1. Flowchart of PLC programming

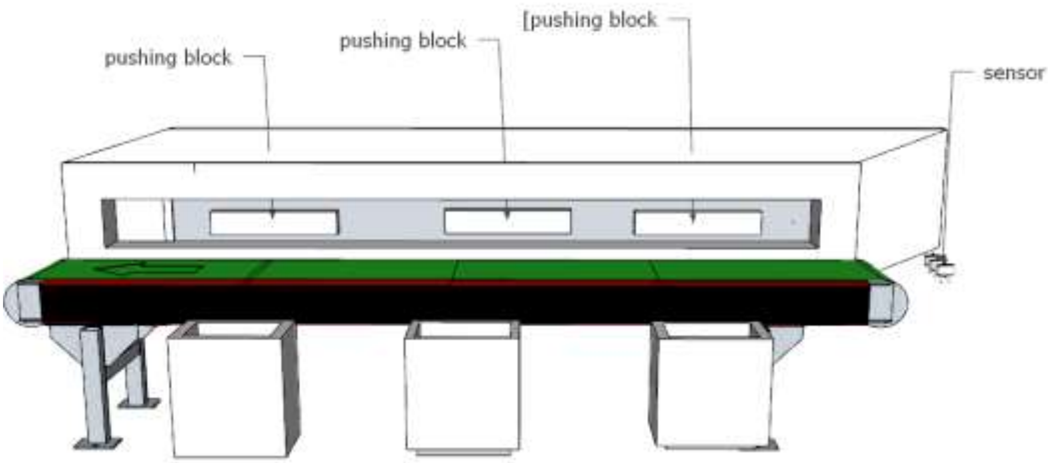

Fig. 2. Prototype drawing

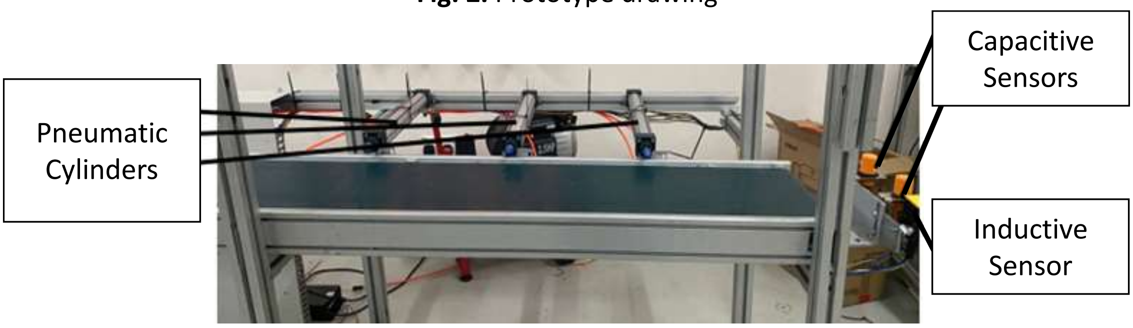

Fig. 3. Side view of the project

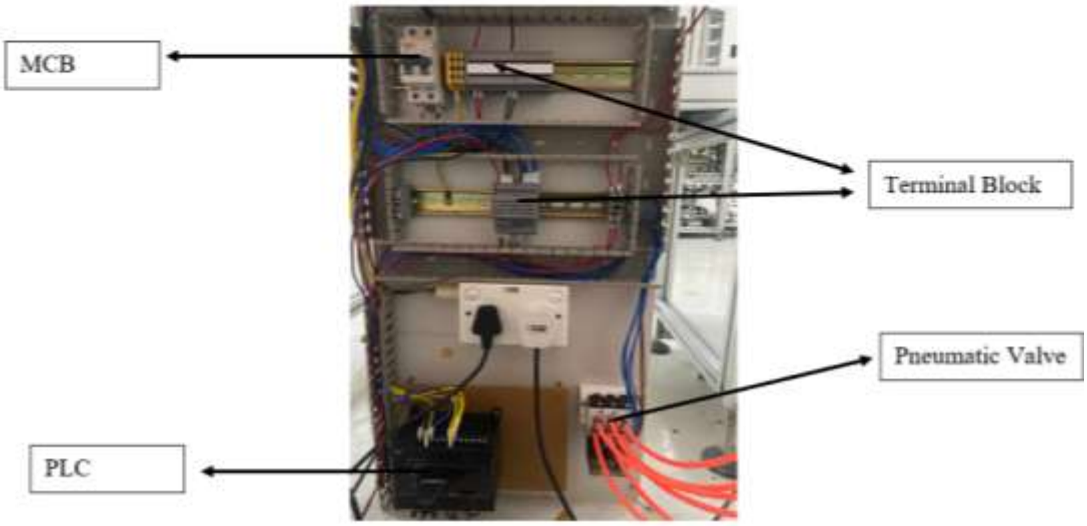

Fig. 4. Connection in electric panel

2.2 Bill of Materials

The bill of materials (BOM) provides information on the components purchased. The materials and their price in Ringgit Malaysia (RM) are summarized as in Table 1.

Table 1
Components list and BOM

No.	Components	Quantity	Unit Price (RM)	Total amount (RM)
1.	Inductive Proximity Sensor	1	350	350
2.	Capacitive Proximity Sensor	2	200	400
2.	PLC Omron CP2E	1	1400	1400
3.	PLC network module	1	450	450
4.	Pneumatic Cylinder	3	450	1350
5.	Pneumatic solenoid valve	1	40	40
6.	Pneumatic Solenoid Valve Connecter	6	4	24
7.	M12 Sensor Connector	3	8	24
	Total			4038

2.3 Sensor Selection and Setting

This section explains the sensor selection and setting, where two types of sensors; inductive proximity sensor and capacitive proximity sensors were used. Table 2 presents the setting of the sensor used to detect the item's materials.

2.3.1 Inductive proximity sensor

An inductive proximity sensor operates by generating a magnetic field and then sensing the resulting change in oscillation amplitude caused by nearby metallic objects. When a metal object approaches, it induces eddy currents on the sensor's surface, affecting its oscillator. These sensors, which operate without physical contact, find application in various scenarios. Figure 5 illustrates an example of an inductive proximity sensor employed to detect metal objects and relay the output signal to a PLC [14-16].

2.3.1 Capacitive proximity sensor

A capacitive proximity sensor monitors the variation in capacitance within a high-frequency oscillator circuit to ascertain the presence or absence of an object, as shown in Figure 6. The detecting surface of the sensor is equipped with two metal electrodes, which together generate an electric field. When an object comes close to the sensor, it influences the surrounding area, causing a change in the oscillator's capacitance [17]. This capability was used to detect glass and plastic materials, transmitting the output signal to the PLC [18-20].

Table 2
Components list and BOM

Sensor	Detect	Model	Setting
Sensor 1	Metal	NI50U-CK40-AN6X2-H1141	This is an inductive sensor which detect metal type of object and the connection is NPN
Sensor 2	Plastic	KI6000	This is a capacitive sensor which detect many types of objects and also plastic and glass. By lowering the sensitivity of the sensor, it will detect plastic and the connection is PNP
Sensor 3	Glass	KI6000	This is a capacitive sensor which detect many types of objects and also plastic and glass. By increasing the sensitivity of the sensor, it will detect glass and the connection is PNP

Fig. 5. Inductive proximity sensor

Fig. 6. Capacitive proximity sensor

2.3 Calculation for Probability of Detecting Materials for the Developed Prototype

The calculation used to determine the probability of success for the developed prototype is necessary to define of the prototype capability in differentiating glass, plastic and metal, for recycling purposes, as presented in Eq. (1) [21,22].

$$Probability\% = \frac{Number of Success}{Number of Test} \times 100\% \tag{1}$$

3. Results

This section presents the result, test, and analysis of the experiment. This was performed by performing several tests to analyse the prototype's performance in separating several test items based on the materials.

3.1 Experiment Design

A total of seven item were tested to analyse the performance of the prototype. Each item was tested 10 times on multiple parts, as shown in Figures 7 to 13. The tested items were plastic water bottle, plastic bag, glass bottle, aluminium can, metal box, metal rod and plastic case.

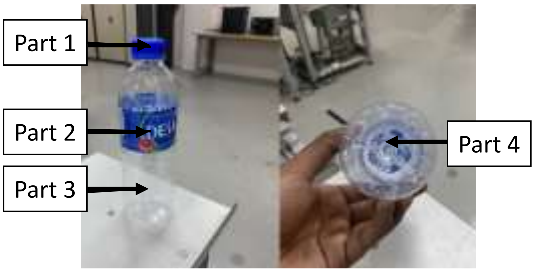

Fig. 7. Test 1: Plastic Water Bottle

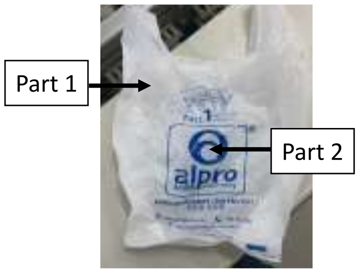

Fig. 8. Test 2: Plastic Bag

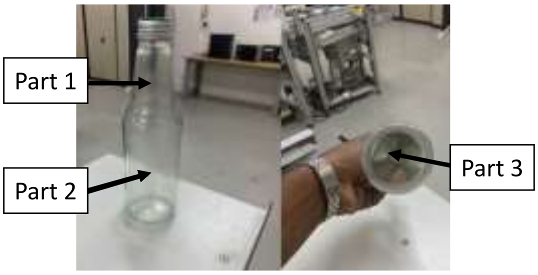

Fig. 9. Test 3: Glass Bottle

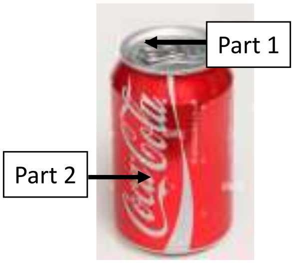

Fig. 10. Test 4: Aluminium Can

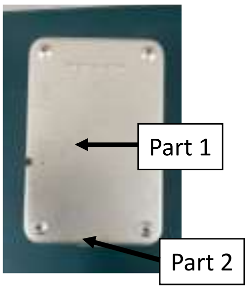

Fig. 11. Test 5: Metal Box

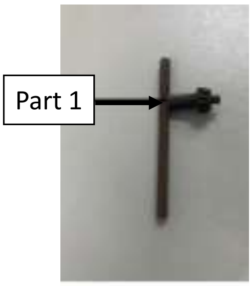

Fig. 12. Test 6: Metal Rod

Fig. 13. Test 7: Plastic Case

3.2 Results

This section presented an overview of the experiment's findings and analysis. Each part was tested ten times, and total number of successful sorting were recorded. Then, the prototype probability of success in detecting material type was calculated. The probability of success for the developed prototype in differentiating the test object's material were summarized in Figure 14.

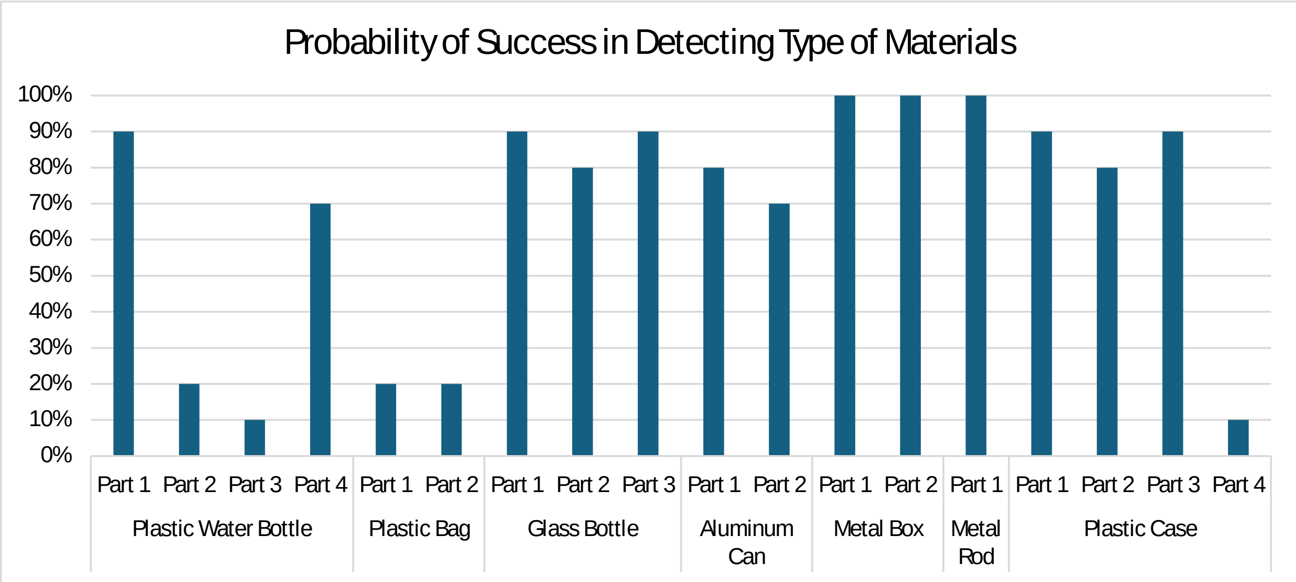

Fig. 14. Probability of success in detecting type of materials

Based on the results above, for the first part from plastic water bottle where the bottle cap was tested, the probability of the prototype to detect the materials type is ninety percent because it is made of hard plastic and is an opaque material. For second part, bottle label was only able to be detected for 20%. This is because the material itself is translucent, which makes it difficult for the sensor to identify it. The third part, which is the centre of the bottle, achieving of 10% only, since it is identical to the label on the bottle, which is see-through. The fourth part is the base of the bottle, which able to be detected for 70% since it is made of strong plastic. However, it is also made of transparent materials, which is the reason why the probability is not 100%.

The second test was done on two parts of plastic bag. The analysis shows that upon testing at both parts, the probability are 20% due to the part is almost see-through, which makes it difficult for the sensor to identify it.

The third test was done on a glass bottle, where three different parts were tested, and the probability in detecting materials are 90%, 80% and 90%. This high probability of success in determining the material type on glass bottle is due to all three sections are made of hard glass and the sensor can identify every part of the bottle with ease.

The fourth test was done on an aluminium can, where two different parts were tested with 80% and 70% of probability in material detection. The high probability is because for metal detection, inductive sensor is used, where it can distinguish the metal object easily.

The fifth test was done on two parts on a metal box. The analysis shows a 100% of detection for both parts, because inductive sensor has better detection on metal type of material.

The sixth test was done on a metal rod, where the metal rod also obtains 100% probability in detection of materials. Similar to the aluminium can and the metal box, the metal detection by inductive sensor is better than capacitive sensor in detecting glass and plastic.

The seventh test was done on a plastic case, where four parts were tested. The probability in detecting materials is 90% for two parts, 80% for one part, and the fourth part which is the base of the plastic casing, was only detected by 10% of probability. The high percentage was achieved for the first three parts were due to hard plastic opaque material, which makes it easier to be distinguished. However, the transparent material at fourth part was not easy to be detected, hence high probability of success in material detection cannot be achieved.

In addition, the limitation of the sensors needs to be considered. Despite the progress that has been made in the current prototype, the research indicates that investing in sensors that are more advanced could considerably improve the capabilities of the system. This might result in better detection range which subsequently enhanced material detection, and increased efficiency in the recycling process. This could be accomplished by replacing the sensors that are now in use with more advanced alternatives, which could potentially incur a higher cost. Such an improvement is in line with the objective of developing a sorting system that is both quicker and more accurate.

4. Conclusions

The goal of this research was to develop a PLC based system for sorting recyclable objects and to determine its probability in determining objects' material. A conveyor was used to move the test item from one location to another. Inductive and capacitive sensors were used to detect the object and providing the input signal for PLC Omron CP2E-N. As a mechanism for pushing the recyclable items for separating it based on materials type, pneumatic cylinders were used, and they are responsible for pushing the test item into the specific box.

Results show that the prototype system can provide different percentage of probability in distinguishing the materials type for the tested items. The high reliability was able to be achieved for hard plastic opaque material makes it easier to be distinguished, However, for plastic's transparent parts, the materials was not easy to be detected. Hard glass type of materials was able to be differentiated most of the times. In addition, metal materials were detected almost in all tests where inductive sensor was used.

In summary, the current implementation is not completed and will be further improved. Future enhancement in increasing the ability to detect the object type is necessary to ensure the high success of developing the PLC-based sorting system for recycle purpose.

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