The Accuracy of Sorting Beverage Cans and Bottles for a Reverse Vending Machine

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ABSTRACT

At present, there are many types of beverage packages such as cans and plastic bottles which lead to a large number of waste beverage cans. Furthermore, throwing beverage cans away without management tends to be an ineffective way to get optimal utilization of resources. Hence, the primary emphasis of this work is on the development of automatic sorting of beverage cans for reverse vending machines. In addition, the accuracy testing of sorting beverage cans by the machine was designed based on three techniques which are easy to implement and which will bring sustainable energy innovations with communities' participation. There are two sampling groups of cans and plastic bottles in the experimental studies. The first group is the group which already has data in the system for using this in a prototype of sorting process. The latter one is the group without data in the system or which has never been used before.

Furthermore, the reverse vending machine has two types of proximity sensors; inductive and capacitive which work together. The experimental results of sorting beverage cans and bottles on two sample groups show that the average accuracy of sorting is 99.20%. The sorting of beverage cans and bottles based on magnetic hinge and barcode provides an average accuracy of 79.20% and 50.00%, respectively. Classifying using the proximity sensor has the fastest operation with an average of 2.66 seconds, followed by barcode and hinge. Those takes 4.01 and 5.21 seconds, respectively.

Keywords: Sorting Beverage Cans, Reverse Vending Machine, Proximity Sensor

1. INTRODUCTION

Throwing beverage cans away without recycling leaves resources unutilized. Many products' packages have been designed for comfort and transport convenience. Properties of packaging materials for use with a foodstuff include strength, and the packaging can be recycled. Moreover, a survey on packaging materials reveals that aluminum achieves among the highest material recycling rates with up to 99.98%. Recycling rates of metal and steel, paper, glass and plastics are 99.81%, 75.22%, 75.06 and 50.53, respectively [1].

Incidentally, if people in communities like education places, temples, attractions, buildings, both in the public and government sectors, provide and promote a garbage sorting system, it will reduce the amount of mismanaged waste. Moreover, the discarded packaging can be sold to recycling shops and is a way to earn money.

The important thing is that recycled packaging materials have prices which are quite different depending on types of materials. Moreover, Fig.1 which shows the pricing data of recyclable waste in Thailand, revealed that aluminum cans have a higher recycling price rate than other cans and plastic bottles [2]. Hence, the purpose of this research is to develop the beginning of garbage sorting system for beverage cans and plastic bottles. In addition, it will get higher recycling price rates from the sorted garbage. It is an effective form of environmental resource management that can be implemented by applying Internet of Things (IoT) for data communication and controlling of the sorted beverage cans for a reverse vending machine.

Fig.1: *Pricing data of recyclable waste on 18 April 2019 in Thailand.*

The sorting of beverage cans is introduced in this paper by using three techniques based on a basic development. The first technique is designed involving part of mechanism, and then selecting cheapest devices which should be easy to find. The second technique uses database and barcodes of beverage cans and plastic bottles. The last technique uses sensors for sorting beverage cans which is convenient.

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Moreover, the experimental studies, together with the measuring accuracy of each technique, are used to be guidelines for developing a reverse vending machine in the future.

2. THEORIES AND METHODS

The goal was development of an automatic reverse vending machine which can classify five types of beverage cans; 1. Small aluminum cans, 2. Medium aluminum cans, 3. Large aluminum cans, 4. Steel cans, and 5. Plastic drinking bottles. In addition, theories and concepts which are related to the development are described in the following section.

2.1 Types of packaging material

There are various important types of metal sheets for packaging which are employed in manufacturing [3].

2.1.1 Tin-plate is 0.15 - 0.5 mm thin steel sheet coated by tin. Another name for this material is black-plate. Furthermore, it can be coated on a single surface or both with tin. Tin-plate has excellent properties of formability, weldability, corrosion resistance and is not toxic.

2.1.2 Tin Free Steel, TFS is a steel plate that is coated with other materials instead of tin. The features of TFS products are paint adhesion, heat resistance, and resistance to black sulphide stain. Moreover, the excellent adhesion properties allow use for food cans, beverage cans and general line cans. In addition, there are three types of coatings which are used to reduce the current production costs.

- Coating with phosphate and chromate mixtures is extensively applied in beer cans and other metal tanks by making a film for coating.
- Aluminium coating has good corrosion resistance to moisture. However, it has a high acid content which is not good for food packaging.
- Coating with chrome and chromium oxide has favourable characteristics because of excellent abrasion resistance, high chemical resistance and it is anti-reflective.

2.2 Light Dependent Resistors

A light-dependent resistor (LDR), or photocell, is a light-controlled variable resistor as well as a photoresistor. In addition, the resistance of a photoresistor depends on light intensity as a result of photoconductivity. It can be applied for light-sensitive detection circuits and control circuits to turn on-off electricity. Creating hole-electron pairs in material can change electrical resistance of LDR from Mega Ohms in the dark, to only a few hundred Ohms when light falls upon it. If incident light on a photo resistor exceeds a certain frequency, electrons will get enough energy to jump into the conduction band because of photon absorption. The results of free electrons and their hole partners conduct electricity, thereby lowering resistance [4].

2.3 Overview of Proximity Sensor

In this research, the theory of electromagnetic methods and sensor devices was deployed to analyse and design the machine components which can classify types of packaging material of beverage cans. Furthermore, the eddy currents have an important role as a part of the structural design for conveying beverage cans into the system. Faraday's law of induction means electromagnetic current will be provided across voltage and electrical conductor in a changing magnetic field. The eddy currents are loops of electrical current induced within conductors in planes perpendicular to the magnetic field. These conductors interact with stainless steel, silver and aluminium [5].

A proximity sensor is an electronic sensor that can detect the presence of objects within its surrounding area without touching anything. Furthermore, the proximity sensor can sense objects by emitting a beam of electromagnetic radiation, usually in the form of infrared light, and senses the reflection in order to determine the object's proximity or distance from the sensor. Proximity sensors have high reliability and long functional life because of the absence of mechanical parts and lack of physical contact between the sensor and the sensed object. Hence, they have been used in numerous applications such as parking sensors, warning systems, conveyor systems, mobile devices and beverage and food can making lines. Inductive proximity sensors which use the principle of magnetic induction to sense a metal object with contactless detection, were applied in this paper. An inductor develops a magnetic field when currents flow through it. Currents will flow through a circuit containing an inductor when the magnetic field through it changes as shown in Fig.2 [6].

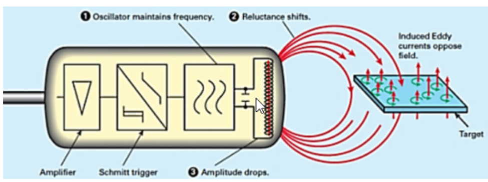


Fig.2: *The principle of inductive proximity sensor.*

In Fig.2, a magnetic field is produced by a precision coil at its heart. Whenever this magnetic field is disturbed by the close proximity of a metal object, an eddy current will be generated that circulates within the target. In turn, loading will be caused on the sensor that decreases the amplitude of the electromagnetic field. If the metal is moved towards the sensor, then the eddy current will vary accordingly. The trigger/amplifier circuitry inside the sensor is used to monitor the amplitude of the oscillator. In addition, the circuitry switches on (or off) the sensor/switch output at certain levels.

The material and size, including the thickness of the target, are an important factor for inductive proximity sensors. Generally, ferrous and nonferrous are two types of target materials for inductive sensors. Ferrous materials such as iron and most steel materials are magnetic in nature while nonferrous materials like zinc, aluminium, copper and brass are nonmagnetic. However, some inductive sensors will work with both ferrous and nonferrous target materials, while others will work only with one type of material.

Types of metal objects which can be detected by the inductive proximity sensor affect the sensing distance. The sensing distance depends on the type of material. Hence, our machine has to find out the factor which can be used to estimate the real sensing distance of each material [7]. The operating distance of the sensor depends on the actuator's shape and size and is strictly linked to the nature of the material as shown in Table 1.

Table 1: *Sensor range in different types of materials.*

Material	Sensor range
Steel	1.00 × Sensing Distance
Stainless Steel	0.6 - 1.0 × Sensing Distance
Aluminum	0.30 - 0.45 × Sensing Distance
Brass	0.35 - 0.45 × Sensing Distance
Copper	0.25 - 0.45 × Sensing Distance

Normal sensing distance (Sn) and sensing distance (Sd) have been employed to estimate distance to the object. Sn is a sensing distance which passed the standard test IEC 947-5-2 which provides the real detected distance. Sd represented the highest detecting distance, which depends on a coil within the inductive proximity sensor as show in Fig.3. In addition, Sd has been used to consider the chance of an unexpected object which might be passed in the detected range.

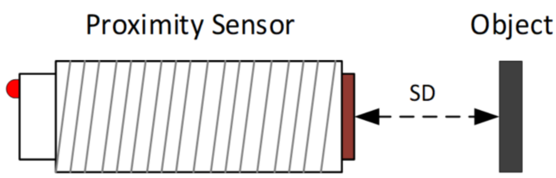


Fig.3: *Sensing Distance of the proximity Sensor.*

2.4 Eddy Current Separators

The principle of an eddy current separator is to apply a powerful magnetic field to separate non-ferrous metals from other waste after all ferrous metals have been removed previously by some arrangement of magnets. The device makes use of eddy currents to effect the separation. However, eddy current separators are not designed to classify ferrous metals which become hot inside the eddy current field. Such heat can lead to damage of the eddy current separator unit belt. Fig.4 shows the eddy current separator applied to a conveyor belt carrying a thin layer of mixed waste. At the end of the conveyor belt is an eddy current rotor. Non-ferrous metals are thrown forward from the belt into a product bin, while non-metals simply fall off the belt due to gravity. Furthermore, eddy current separators may use a rotating drum with permanent magnets, or they may use an electromagnet, depending on the type of separator. The eddy current separator is one of the most important machines which is used in recycling process. Recycling processing can be done for aluminium, plastic, rubber, municipal solid waste and many other materials. In aluminium recycling, the scrap waste aluminium metal can be reused in products after the initial production. Removing non-ferrous metals from waste material is difficult task industries are facing. The eddy current separator is suitable to be employed for solving these problems [8].

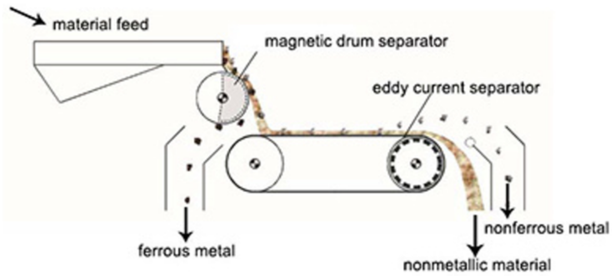


Fig.4: *Diagram for eddy current metal separating machine [9].*

3. SYSTEM DESIGN

This reverse vending machine consists of many sensors used when receiving cans into the system and in the checking system. The checking system has a weight sensor (load cell) and an infrared sensor. There are many main parts that are working simultaneously, such as conveyer set, lid controller set for incoming can control lid (Lid1), can pressing set using 350-watt DC motor, lid controller set for outgoing can to classifying box (Lid2), and hinge set for can classifying to classifying box. The mentioned parts are shown in Fig.5.

There are two main structures in the reverse vending machine, one size classification, and for type classification. This work is focusing on type classification, but details about size classification are mentioned as well because the price depends on the size of the cans or plastic bottles. From the information collected, generally beverage cans can be classified into five categories showed in Table 2.

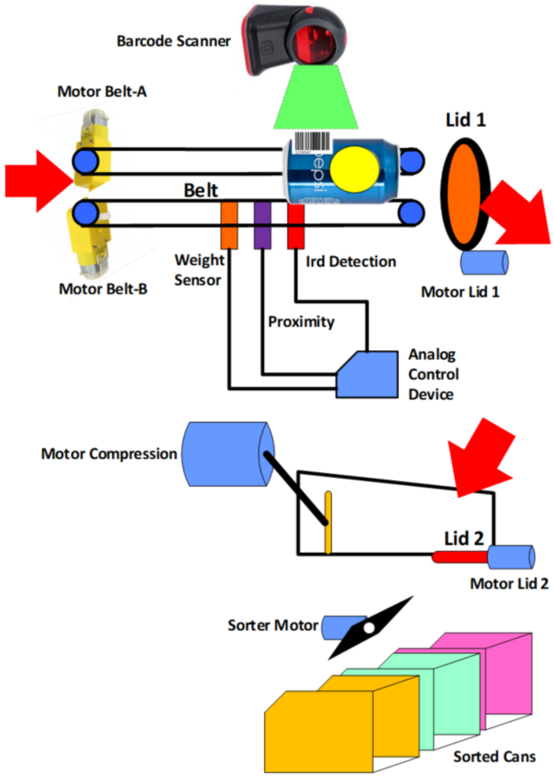


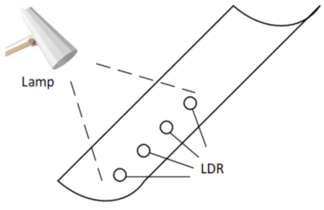
Fig.5: *Parts of automatic reverse vending machine.*

Table 2: *General shape information of beverage cans.*

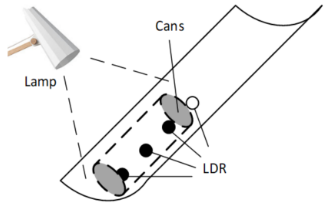
Example Product	Height (mm)	Diameter (mm)	Weight (gram)
	115	60	20.00
	130	50	16.65
	145	50	16.85
	170	60	32.35
	100	50	35.55

3.1 Can classification

In this work, the machine senses the can size by using four LDR installed in a row with significant distances between the sensors, as show in Fig.6. The distances measured from the bottom edge of the machine are 60, 100, 130 and 160 mm. respectively. When the incoming cans move to the receiving tray, the cans block light shining on the LDR sensors according to their height. The sensors with the locations lower than the height of the can will not receive enough light so the LDR sensors become high resistors. One sensor is connected to an input pin of GPIO of a single board computer in order to allow the system to receive and analyse the height of the incoming can.



(a) No blocking of light



(b) Blocking of light

Fig.6: *LDR sensor installation.*

Table 3: *Interpretation of data from LDR sensors.*

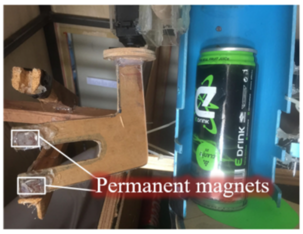
Sensor	Position	Meaning
LDR1	60 mm	Can/ bottle enters to the system
LDR2	100 mm	The height of can is 100-120 mm
LDR3	130 mm	The height of can is 130-150 mm
LDR4	160 mm	The height of can is more than 150 mm

3.2 Type classification of drinking water can

When classifying drinking water cans, in this work, aluminium and zinc cans are considered. Both types of materials are in a metal group, but they have different prices. Classification techniques chosen for this study are

1) Classifying using hinge is based on the fundamental idea of a permanent magnet. The incoming can is pulled up to the hinge driven by a small servo motor. When it comes in the receiving tray, the LDRR sensor installed at first position, shortest distance with 60 mm, can sense that it is a can coming into the system. The hinge motor is driven to contact the can in the receiving tray. In Fig.7, after the hinge moves back to the previous location, the can sticks on the hinge because of the magnetic force. The sensor is checked again. If the sensor cannot sense any can, this means the last incoming can is a metal can. But if the sensor still senses a can on the receiving tray, that means the last incoming can could be zinc can, plastic can or non-metal. For the conveyor part, a U-shape stick is introduced to push the classified can into the corresponding storage box while the hinge is moving back to the beginning position. An outline flowchart of sorting with permanent magnets on hinges is shown in Fig.8.

2) Classification using barcode requires preparing both hardware and software. There must be a barcode scanner and a database of barcode. The read code is used for searching a database, so preparing the database before using it is required. All information about cans has to be filled into the database, including, types of materials, weight, and buying prices.



(a) Cans come in the receiver.

(b) Hinges move to tap.

(c) Hinges move lift up.

Fig. 7: *Hinges and permanent magnets.*

The advantage of using barcode is the accuracy of classification of the incoming cans. For this research I decided to install the barcode reader at the can receiving section. The barcode with 20-line scanning rays, and in three different (vertical, horizontal, and diagonal) are used. This barcode reader makes it easy to scan the barcode and covers the whole barcode on the can. The barcode reader is installed above the conveyor belt as shown in Fig.9. An outline flowchart of sorting via barcode and database is shown in Fig.10.

3) For classification using a proximity sensor, a proximity sensor is installed under the conveyor belt which has a distance from the incoming can placed on the belt. The distance of sensor is constant at 15-20 mm. as shown in Fig.11. The principle of the inductive proximity sensor is the function of on/off switch, but because in this research the objective is to classify the type of drinking water cans, especially the ones composes of metal and aluminium, sensors deployed in this work need to be able to perform high definition sense and produce different levels of outputs. In this work, inductive proximity sensors with 0-10 VDC and 4-20 mA current analogue output [10] were used. This technique of sorting has a sequence of work steps as shown in Fig.12.

1. Infrared sensor
2. Belt
3. Weight sensor
4. Proximity sensor

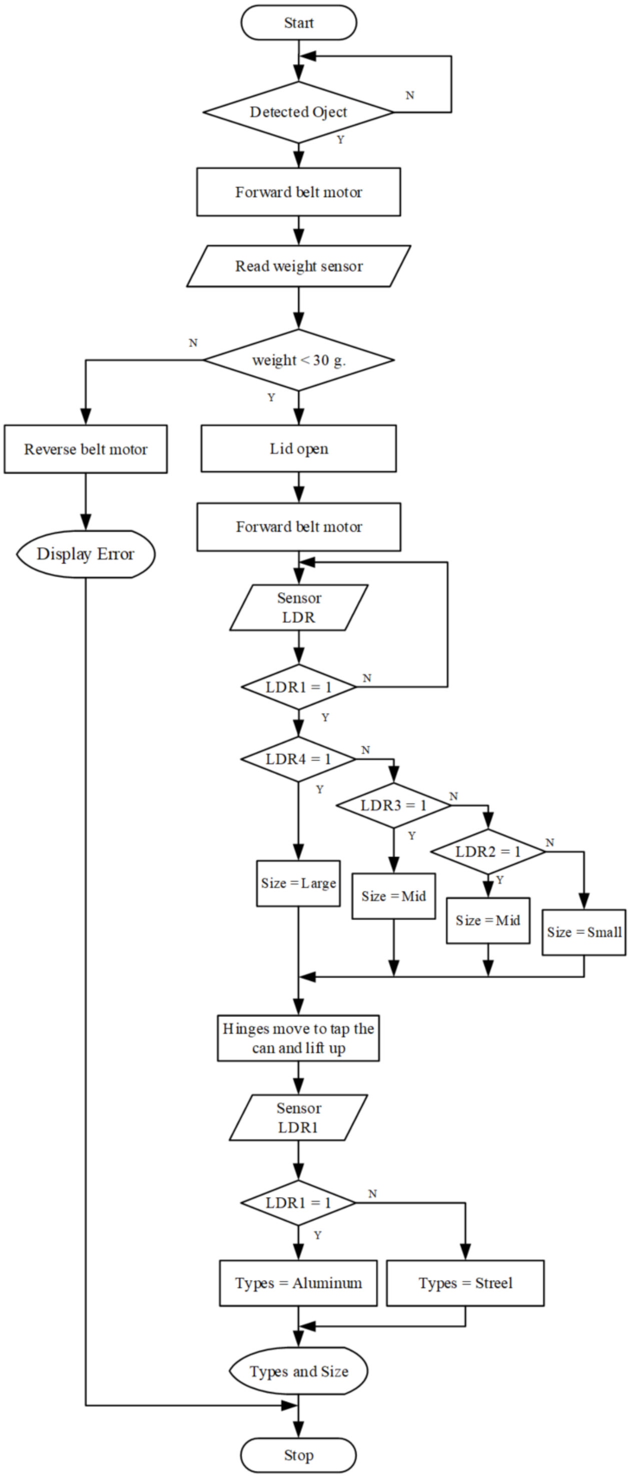
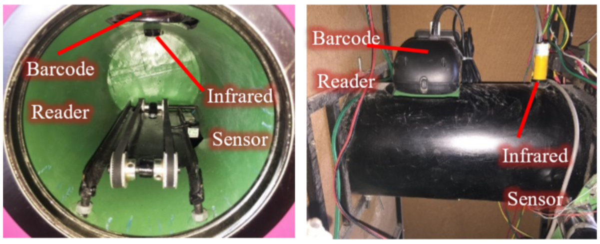


Fig. 8: *Flowchart of sorting with permanent magnet hinges.*

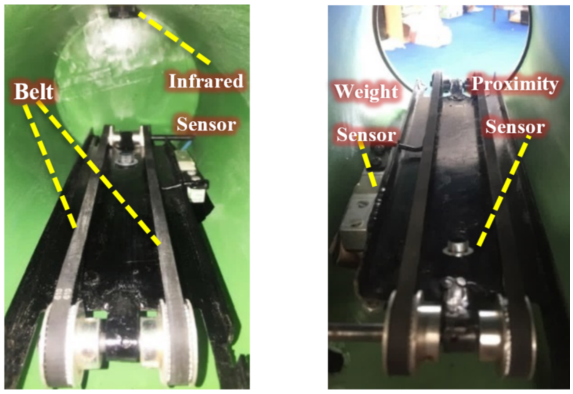
4. RESULTS

To test the performance of the drinking water can classification techniques, the cans were divided into two groups: 1) cans with data already in the database and 2) cans without data in the database. The results can be divided into different groups according to test-



(a) Front view (b) Right side view

Fig.9: *Barcode Scanner Installation.*



(a) Front view (b) Back view

Fig.11: *Sensor location at the conveyor belt.*

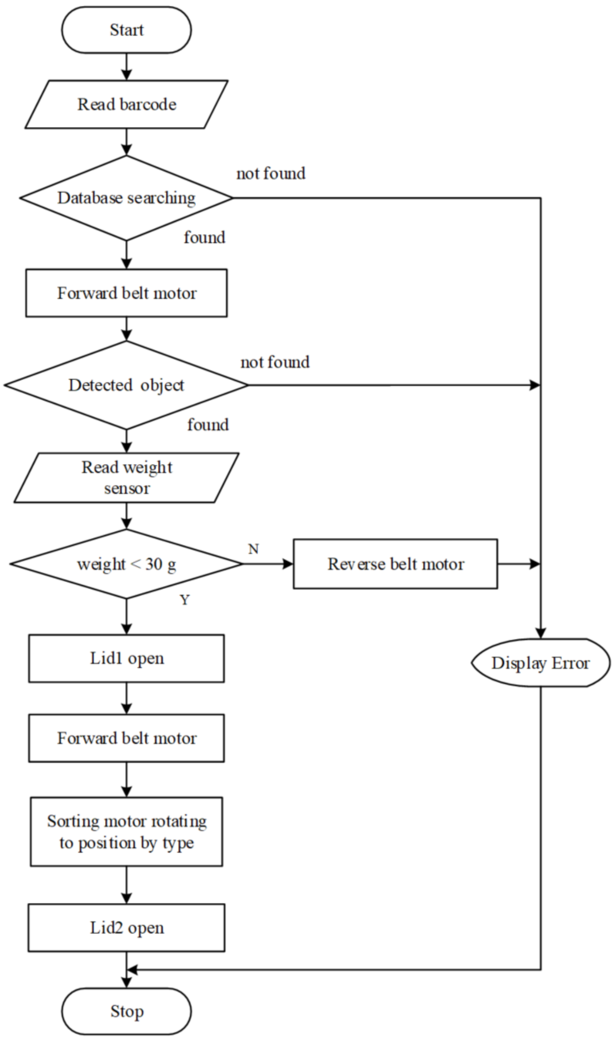


Fig.10: *Flowchart of Sorting via barcode and database.*

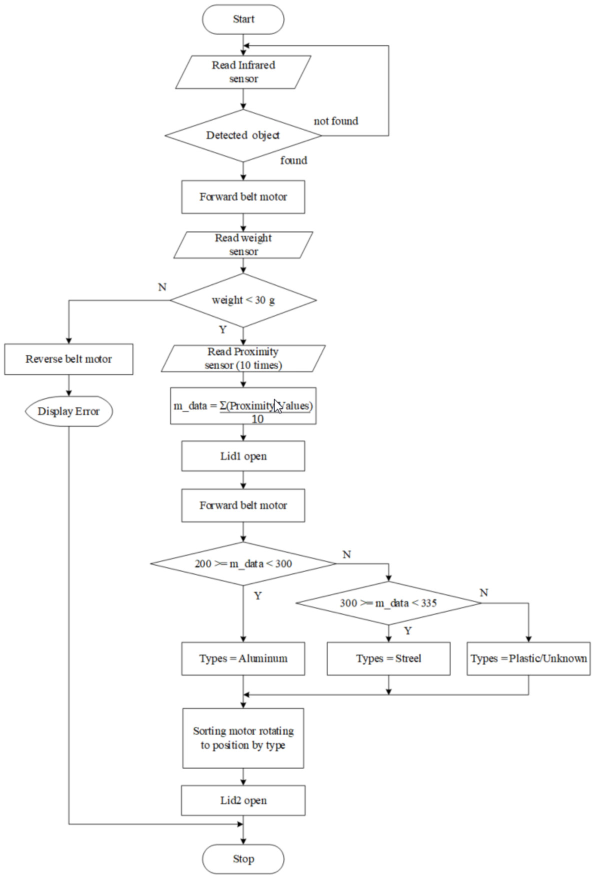


Fig.12: *Flowchart of Sorting via Proximity sensor.*

ing methods as shown below.

4.1 Performance of classification using permanent magnetic hinge

This test classifies five different sizes of cans which are small aluminium can (115 mm height), medium aluminium can (130-145 mm height), big aluminium can (170 mm height), iron can, and 500-600 ml drinking water bottle. The objects were inserted into the machine one-by-one with random order, and then the result was read on the LCD screen as show in Fig.13.

Fig.13: *Results of the classification using permanent magnet hinge.*

Table 4: *Test results for can classification using permanent magnet hinge.*

	Number of tests	Worked correctly	Proximity
Small AL	50.00	50.00	100.00
Medium AL	50.00	50.00	100.00
Large AL	50.00	50.00	100.00
Iron	50.00	47.00	94.00
PET Plastic	50.00	0.00	0.00
Average	50.00	39.40	78.80

Table 4 shows that the proposed can classification machine using a permanent magnet hinge can receive cans into the system and count the amount of the three different sizes of cans with 100% accuracy. But this type of can classification cannot classify plastic bottles because this machine version was developed without plastic bottle classification design.

For iron can classification, there were three errors which occurred during the test, and it caused error in the classifying process. The iron can was driven to move while the U-shape stick was pushing the can into the storage box. As a result, the iron can was pulled by the magnetic hinge in an unexpected position as shown in Fig.14. The result of iron can classification was 94.00% accuracy.

Overall, automatic can classification using a permanent magnet is hinge collaborating with LDR sensor can classify different types of cans with 78.80% averaged accuracy.

4.2 Performance of can classification using barcode reading

This machine was based on barcode reading, and was the successor to the classification machine using a magnetic hinge. The test setting was the same as previous test. Five different types of objects were used. The machine was prepared by entering the data needed for barcode reading into the database. This test had 50 objects for each type (five types: small, medium, and large aluminium cans, iron cans, and plastic bottles). The cans or bottles were inserted into the machine one-by-one, and the results were observed on the LCD screen as show in Fig.15.

Results in Table 5 showed that the automatic can classification using barcodes can receive and correctly

Fig.14: *Result of a successful can classification using barcode.*

Fig.15: *Result of a successful can classification using barcode.*

Table 5: *Test results for objects classification using barcodes.*

	Number of tests	Worked correctly	Proximity
Small AL	50.00	50.00	100.00
Medium AL	50.00	50.00	100.00
Large AL	50.00	50.00	100.00
Iron	50.00	50.00	100.00
PET Plastic	50.00	50.00	100.00
Average	50.00	50.00	100.00

count number of five different sized objects; three sizes of aluminium cans, iron cans, and plastic bottles. The accuracy was 100%.

4.3 Performance of can classification using proximity sensor

The functions of the machine were examined by analysing the signal received from the Analogue Control Device (ACD). We found that the responses to metal objects which are iron and aluminium cans, are significantly different. The detail is described in the following paragraphs.

1) In testing with 10 aluminium cans, with different sizes, 50-60 mm width, and 115-170 mm height, we found that the data from the ACD sensor was between level 296 and level 335 out of a total 1024 levels, as shows in Fig.16.

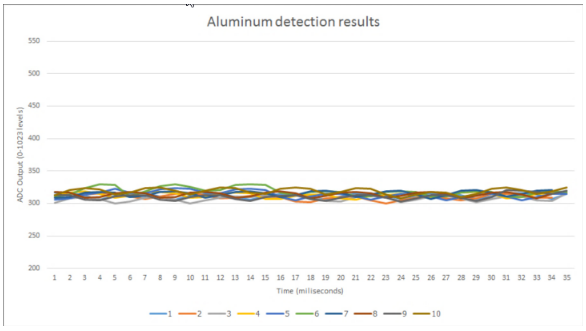


Fig.16: *Data from sensor when aluminium can is detected.*

2) When testing with 10 iron cans, with 50-60 mm width and 95-130 mm height, we found that received data from the ACD sensor is in between level 233 and level 302 out of a total of 1024 levels, as show in Fig.17.

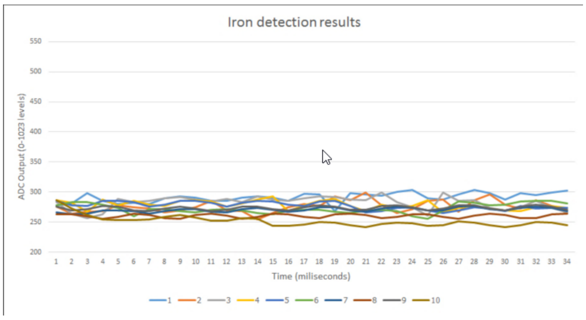


Fig.17: *Data from sensor when an iron can is detected.*

3) In testing with 10 other non-metal objects which were glass, paper, plastic, and no object, we found that the data from the ACD sensor was between level 527 and level 544 out of a total of 1024 levels, as shows in Fig.18.

Fig.18: *Data from sensor when no object was found.*

All in all, the inductive proximity sensor with analogue output as implemented in the machine could classify iron and aluminium into different groups. In addition, to complete performance-comparison analysis, another type of sensor was introduced. We deployed a capacitive proximity sensor to detect drinking water bottles. This sensor is able to sense non-metal objects made of materials such as paper, water, and plastic. The output of the sensor is on/off logic.

The test results showed that the capacitive proximity sensor is very sensitive, and it also responds to metal objects as well. So both signals from inductive and capacitive proximity sensors were used in order to separate iron object from aluminium objects. A capacitive proximity sensor was used to detect drinking water bottle when the inductive proximity sensor could not detect any object. The responsibility test of both sensors is shown in Table 6.

Table 6: *Output signal of proximity sensor when an object is detected.*

Types	Proximity Sensor Output	
	Inductive (0-1023)	Capacitive (Logic)
Small AL	296-335	On
Medium AL		
Large AL		
Iron	233-302	On
PET Plastic	530-545	On
None	527-544	Off

Can classification using proximity sensor could classify five different types of objects; iron can, plastic bottle, and three different sizes of aluminium cans. It also accurately classified objects according to materials: iron, aluminium, and plastic. The averaged accuracy was 100% for all types of cans, but the proximity sensor could not detect sizes of objects. The test results are shown in Table 7.

Table 7: *Can classification using proximity sensor.*

	Number of tests	Worked correctly	Proximity
Small AL*	50.00	50.00	100.00
Medium AL*	50.00	50.00	100.00
Large AL*	50.00	50.00	100.00
Iron	50.00	50.00	100.00
PET Plastic	50.00	48.00	96.00
Average	50.00	49.60	99.20

4.4 Performance of unknown object classification

This test is a classification of 50 objects without their information in the database. The objects were put into the machine and then classified by three different techniques, magnetic hinge, barcode, and proximity sensor. The results are shown in Table 8.

Results in Table 8 shows that when new types (unknown) of cans or bottles were classified by the magnetic hinge technique, the machine could classify aluminium and iron cans but could not classify plastic bottles. The average accuracy was 79.60%.

When object classification using a barcode reading technique was used, the machine could not classify

Table 8: *Classification of unknown objects.*

	Magnetic hinge	Barcode	Proximity
Small AL	50.00	0.00	50.00
Medium AL	50.00	0.00	50.00
Large AL	50.00	0.00	50.00
Iron	49.00	0.00	50.00
PET Plastic	0.00	0.00	48.00
Average	39.80	0.00	49.60
Percent	79.60	0.00	99.20

cans or bottles when can or bottle information was missing from the database. As a result, the accuracy is 0%.

Using a proximity sensor for object classification in the machine allowed it to be able to classify the unknown cans and bottles. The machine could classify the cans and bottles by detecting the materials. The average accuracy was 99.20%.

4.5 Processing time classifying objects

The samples for this experiment were bottles and cans with five different sizes. There were 20 bottles or cans for each size, so there were 100 bottles or cans in total for the test. In order to investigate the average processing speed of the three proposed methods, the starting time was set when a can or bottle was inserted into the machine, and the ending time was set when the bottle or can was already classified.

Table 9: *Processing time for classifying objects.*

	Magnetic hinge (sec.)	Barcode (sec.)	Proximity (sec.)
Small AL	5.22	3.78	2.62
Medium AL	5.21	4.33	2.66
Large AL	5.21	4.35	2.67
Iron	5.22	3.77	2.65
PET Plastic	5.22	3.81	2.67
Average	5.21	4.01	2.66
S.D.	0.01	0.30	0.20

5. CONCLUSION

Performance analysis of the automatic object classification techniques has been described. Three techniques were proposed which are classification of cans and bottles using a magnetic hinge, barcode reading, and a proximity sensor. The objects used in the tests were divided into two groups; objects with information in database, and objects without information in the database. We found that the classification using a magnetic hinge could detect sizes and weights of cans and bottles because of the collaboration with LDR sensors. Moreover, it could separate aluminium cans from iron cans of both groups. However, this technique could not detect water bottles. The average accuracy was 79.2%. This technique took the most time for sorting.

Classification using barcode reading can classify the cans and bottles in group 1 with 100% accuracy, but it could not classify any can or bottle from group 2. As a result, the average accuracy was 50%.

When the proximity sensor technique was applied, we found that the machine could classify cans and bottles well from both groups. The machine could directly detect types of materials of cans and bottles, but it could not detect the sizes of all of them. The average accuracy was 99.20% and it spent the least amount of time in the sorting process compared to other methods.

Future suggestions for enhancing the performance of the machine would include using various types of sensors using a barcode technique and a proximity sensor together could give more accuracy in the classification. When a proximity sensor detects new type of can or bottle, the information of the new type could be automatically recorded into the database.

The magnetic hinge technique provides simplicity and low cost, but because it is a mechanical device, errors can happen more often compared to using the proximity sensor technique, where no part contacts can or bottle.

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