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Development of a low-cost reverse vending machine for clear plastic bottles and aluminum cans

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ABSTRACT

The trend of environmental conservation has become an interesting topic over the past decade; a lot of waste has been recycled to preserve the environment. The objective of this research was to design and develop a low-cost reverse vending machine to support solid waste management in Khao Rup Chang Municipality, Songkhla province, Thailand. For the first step, clear plastic bottles and aluminum cans were classified using a color sensor and a proximity sensor. Next, coupon slips and earned points could be printed out for customers to exchange for money or rewards under the project. All of the mentioned steps were controlled by a microcontroller. The experiments were conducted using 1280 samples. The results showed that the accuracy of sorting three types of materials: clear plastic bottles, aluminum cans, and both materials, was 96.50%, 100%, and 95.25%, respectively. The processing time for each container was 5.52 s on average.

Keywords: waste separation; smart bin; recycle trash; reverse vending machine

1. INTRODUCTION

Recycling is an important process in waste management to reduce the amount of solid waste. At present, people in Thailand are encouraged to sort their waste before disposal. According to the ministry report, there were 25.37 million tons of Thailand's solid waste per year in 2020, but 8.36 million tons per year, or 32.95% of waste could be reused (Pollution Control Department, 2020). It was also found that solid waste management could be improved for two reasons. First, solid waste management was announced as a national agenda. Second, the government has encouraged communities to use a waste sorting mechanism as much as possible. For these reasons, the amount of waste utilization has been increased. However, waste quantities are expected to increase every year, so the process to manage waste from inception is a key factor. Many organizations and communities have realized the importance of managing waste collection and sorting through the cooperation of people in the community. Various departments organized a charity event or some activities, such as the garbage bank project and the green activity (Friedberg and Hilderbrand, 2017).

In many countries, such as India (Balubai et al., 2017), Malaysia (Gaur et al., 2018), and Thailand (Tiyarattanachai et al., 2015), technology has been increasingly applied to waste management because of human error. Besides, there are other advantages, such as labor cost reduction and avoidance of human confrontation. For the mentioned reasons, various technological innovations have been developed up to the present. One of the innovative trends is the take-back machine. It is currently divided into three sorting principles: manual sorting by an operator (Sambhi and Dahiya, 2020), indirect rejection by reading bar code labels (Sinaga and Irawan, 2020), and direct separation by a body material of each container (Tachwali, 2005).

However, each sorting principle has its pros and cons. Manual sorting by an operator is uncomplicated and inexpensive, but it is prone to inaccuracy (Tomari et al., 2017). Indirect rejection by reading bar code labels, which is applied in many studies, is easy, fast, and accurate. However, it is expensive and more complicated; it requires a bar code database that needs to be updated regularly because data that are not available in the database cause errors in the system (Sinaga and Irawan, 2020). The third principle is a knowledge-based technique. Features such as size, weight, and type of material are used to sort the objects. One advantage of the third principle is flexibility. When a new object is put into the system, it can still correctly operate even without any updated data. In other words, it is very fast and does not depend on a database. However, the main disadvantage is the low accuracy (Wahab et al., 2006).

Even though the system design for reverse vending machines used in the above mentioned research are different, all are developed to be fast, low-cost, and human-dependent to support a wide variety of waste containers in communities. For our automatic system development, the focus of the machine design is practicality, durability, and ease of access with low energy consumption. Moreover, its cost is considered an important factor for community application, especially in communities with a high density of people. For the results of this machine, accepted clear containers and aluminum cans are sorted by their color readouts and electromagnetic readings. As such, we expect positive responses from users for its cost-effectiveness and ability to support all types and brands of containers, even in imperfect conditions. Indeed, the development of this innovation will be used in the community of Khao Rup Chang Municipality, Songkhla province, Thailand. Since the main role of our machine is the classification of beverage containers, the type of sensors to be used is crucial to this work. Hence, we are going to describe three sensors used in this research: infrared reflectance, color, and proximity sensors.

An infrared reflectance sensor is a non-contact object inspection sensor. This sensor consists of an infrared transmitter and a receiver and relies on the operation of the photo reflective sensor. As the transmitter emits infrared signals all the time, and when the signal hits an object, its reflection is detected by the receiver (Figure 1 (a)). The fundamental principle of this infrared sensor is to detect obstacles (Boaz et al., 2016) and its distance can be calculated using the obstacle distance calculation algorithm (Wang and Liu, 2008). When there are obstacles or objects, the signal is reflected back to the receiver cut a certain angle. Hence, the distance can be determined, or the presence of an object can be detected. In this research, the beverage container size was measured by calculating the distance between the object and the sensor.

The TCS230 is a color sensor, which is often applied to robots or microcontrollers. It can also be used to track and sort objects by their colors. The TCS230 color sensor has a photodiode array arranged in 8 x 8 array matrices. The photodiode array has 4 functioning filters: 16 photodiodes with red filters, 16 photodiodes with blue filters, 16 photodiodes with green filters, and 16 photodiodes with no filters, as shown in Figure 1 (b). The output is a square wave (50% duty cycle) with a frequency that is proportional to light intensity (irradiance). The full-scale output frequency is scaled by one of three preset values via two control input pins.

A proximity sensor, or proximity switch, is also a non-contact object sensor chosen for the system. It transmits electromagnetic field and checks for a change in the returned signal. It is mainly used for level, size, shape, and position detection applications, which are typically used instead of touch switches (limit switches) because their lifetimes and target object detection speeds are better than that of switch-based devices. In this work, it was used to determine the distance from the object, as shown in Figure 1 (c). For mechanical contact, this proximity sensor has outstanding features such as detection without touch, harsh environment, accuracy, and fast responsive property, among others. An object detection distance is generally between 4-40 mm, depending on the sizes and types of sensors (Himes, 2020). The distance that the sensor can detect an object depends on the object type and sensor diameter. Assuming that the sensor diameter is constant, an object type can be determined by multiplying the constant factor by the distance between the object and sensor (the sensing distance), as shown in Table 1 (Hornung and Brand, 2012).

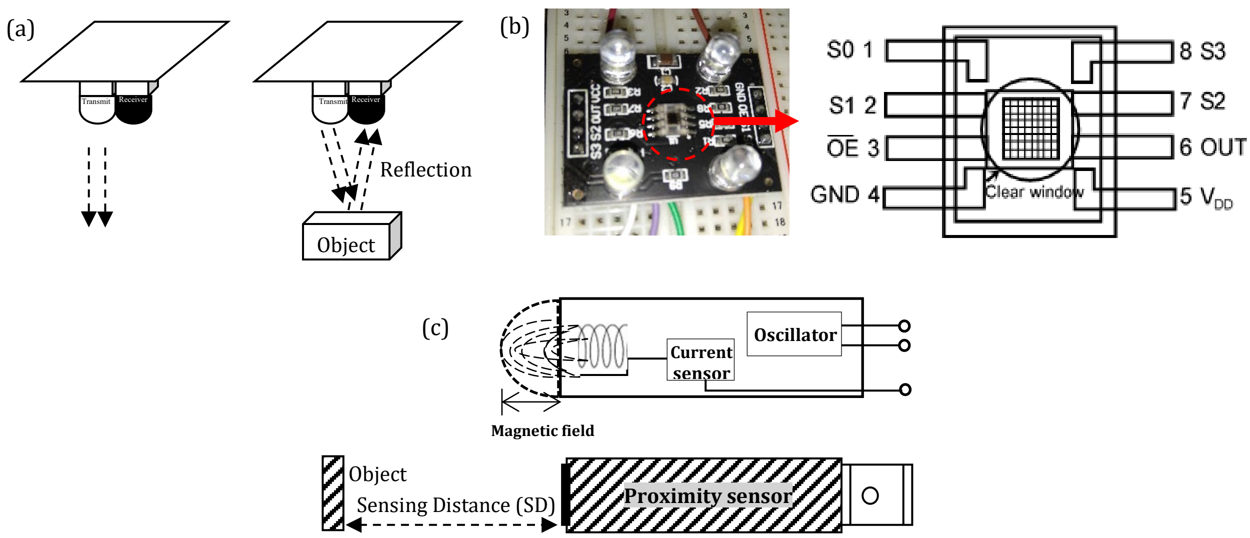


Figure 1. Three sensors used in this work. (a) Infrared sensor, (b) color sensor: TCS230, and (c) proximity sensor

Table 1. Sensor range of various materials

Target material factor	
Material	**Sensor range**
Iron or steel	1.00 x Sensing distance.
Nickel chromium	0.90 x Sensing distance
Stainless steel	0.85 x Sensing distance
Brass	0.50 x Sensing distance
Aluminum	0.40 x Sensing distance
Copper	0.30 x Sensing distance

2. MATERIALS AND METHODS

2.1 Types of beverage containers

In general, a reverse vending machine is designed to take weight and types of materials as input. In this study, size, weight, and types of containers were considered, and clear plastic bottles, glass bottles, aluminum (Al) cans, and iron cans, which can be found everywhere in any community in Thailand, were used. Shown in Table 2 are the size metrics (height and diameter).

Table 2. General shape information of beverage containers

Product	∅ (mm)	Weight (g)	Height (mm)
Clear plastic bottle (S)	60	10-14	150
Clear plastic bottle (M)	60	15-17	210-240
Clear plastic bottle (L)	85	28-30	290-320
Glass bottle	62-80	> 30	150-350
Aluminum can (S)	50-60	16-20	115-130
Aluminum can (L)	50-60	16-32	140-170
Iron can	50-60	35-38	100-120

2.2 System design

The proposed system shown in Figure 2 contains two modules, namely a mechanical module and an electrical module. Both were assembled on a 60 x 60 x 180 cm steel cabinet (Figure 3 (a)), which was considered a suitable size for transportation and installation in various community locations. The differences between our design and other systems are as follows. Our system supports many brands and models of beverage containers as the system directly checks the type of material of containers, and the machine design is economical because inexpensive equipment was used, the design allows for low power consumption, and the system worked without a database. For the machine operation, there is a semi-circular curved sheet that is served for left and right rotation, as shown in Figure 3 (b). A container is placed on the curved sheet supported by a semi-circular cylinder, and the reading unit classifies each type of container. The working steps of the system are shown in the flowchart in Figure 4.

For all types of bottles, the machine first checks if a container has leftover liquid, which may cause the machine to be out of order. In this case, the container will be categorized as an unqualified object and is returned to the users. Depending on the type of container, the semi-circular rotates 90° to the left for aluminum cans and to the right for clear plastic bottles, dropping the container into the compression unit to be transported to the collection pit. However, when a container is neither of the two mentioned types, the machine returns the object to the user by notifying them through an LCD screen. In addition, the system is designed to fascinate users. More specifically, some incentives are provided for the users, depending on their membership status. For non-members, the user can only get a coupon that is calculated based on the size of bottles. This coupon can be exchanged for cash or other rewards depending on the community or can be donated to a charity. For members, they can choose to get a coupon or accumulate points stored in the cloud system, which can be exchanged for incentives.

2.3 Experimental set-up

As beverage containers in our scope were classified into transparent plastic bottles and aluminum cans, in our experiments, we focused on separating clear plastic bottles from opaque bottles and aluminum cans from iron cans. Various types of containers were tested, such as clear plastic bottles, opaque bottles, glass bottles, clear colored bottles, metal cans, and aluminum cans (Figure 5). To classify those types, the reading unit includes two sensing devices: the color sensor and the aluminum sensor, which are installed as shown in Figure 3 (b). The system receives data from the sensors and decides whether to accept or reject those containers. For classification processing, two parameters need to be investigated. The first parameter is a color threshold for discriminating clear plastic bottles and the second parameter is a range of inductance. Once, the parameters are set, the performance of the machine will be investigated.

Focusing on two issues of investigation: accuracy of classification and user acceptance, five experiments were set. For accuracy of classification, three experiments were conducted. For user acceptance, there are two experiments: processing time and system status. For the first three experiments, 50 samples of each type were used for testing: 400 samples for each experiment, which totals to 1200 samples for the experiments. For the fourth experiment, 80 samples were tested. For the last experiment, we only monitored the aforementioned experiments.

2.3.1 Color sensor

This experiment aimed to set up the color threshold of the system. The sensor was installed at the base of the reading unit. TCS230 was used to separate the clear plastic bottles from the opaque containers (high density polyethylene (HDPE), paper, metal, etc.) by setting the system expectation to only accept clear plastic bottles. In the other cases, the expectation was rejection. For classification, a user placed a container vertically into a reading slot. In the system, the light-emitting diode (LED) was turned on to control light condition. Next, a set of 400 samples was tested to evaluate the performance of the color sensor.

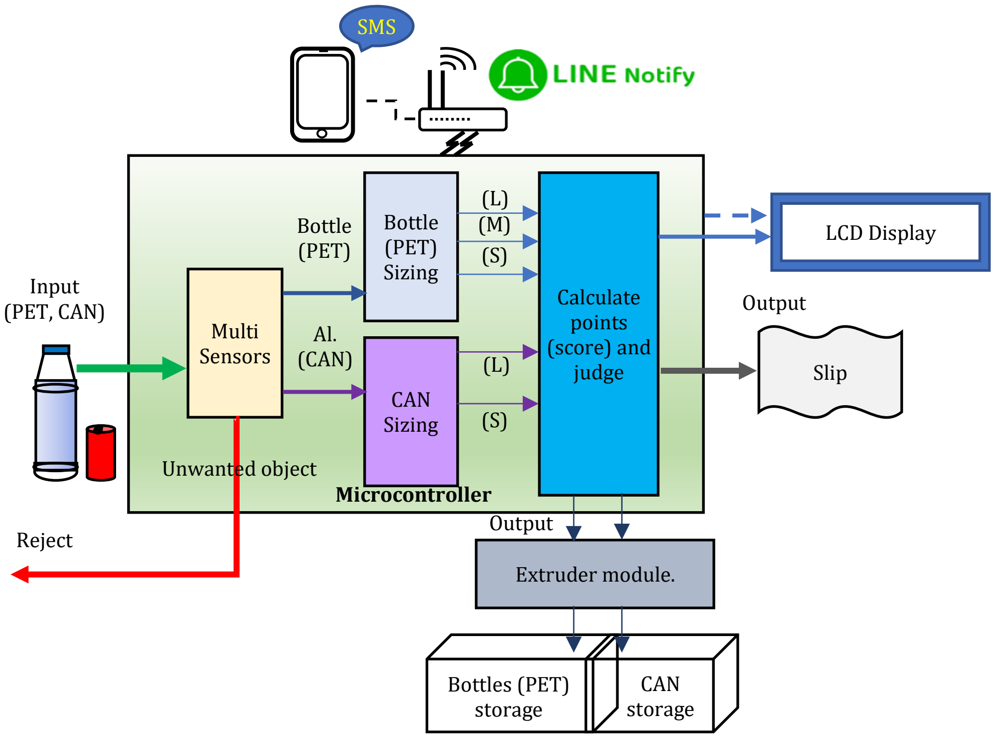


Figure 2. Overview of the reverse vending machine

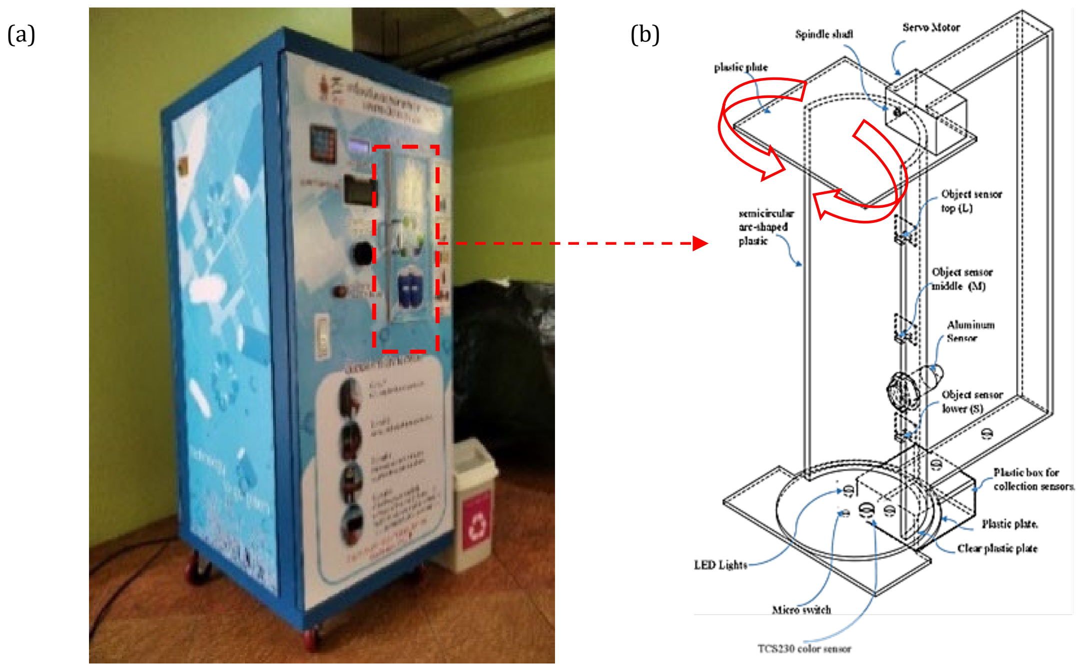


Figure 3. Machine design; (a) The successfully developed prototype, and (b) Internal structure of a reading unit

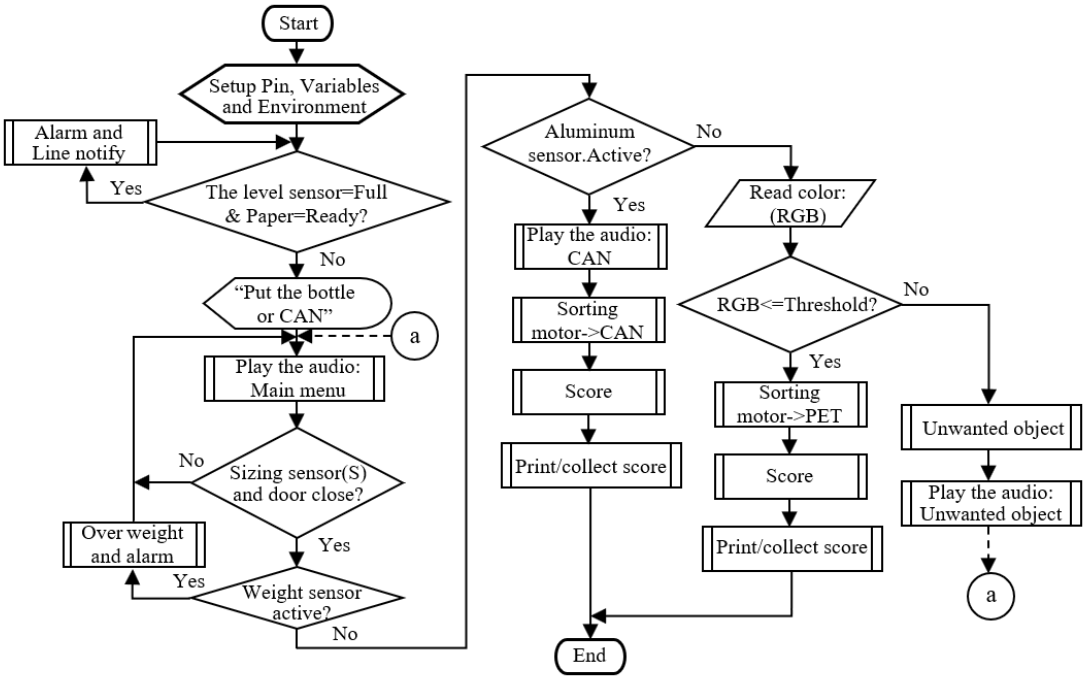


Figure 4. Flowchart of the operation of a reverse vending machine


Small PET bottle


Medium PET bottle


Large PET bottle


Small aluminum can


Medium aluminum can


Large aluminum can


Clear colored bottle


Iron can


HDPE bottle

Figure 5. Various types of containers

2.3.2 Proximity sensor

A proximity sensor was used to separate aluminum containers from other containers. Based on the principle by induction of electromagnetic fields, metal and non-metal objects had very different inductances. To investigate the inductance property, three cases were investigated in our experiment: aluminum can, iron cans, and no objects. Once the inductance parameter was set, the proximity sensor experiment was conducted with a new set of 400 samples. In this experiment, we set the system expectation to only accept aluminum cans. In the other cases, the expectation was rejection.

2.3.3 Color and proximity sensors

In this part, the classification efficiency of the machine was evaluated. This experiment is a practical test. We placed the machine in a real community location. The color sensor was used to classify clear plastic bottles, and the proximity sensor was employed to classify aluminum cans. For the experimental set up, we set the system expectation to accept both clear plastic bottles and aluminum cans, and to reject the other cases. For each type of beverage containers, 50 beverage containers were tested (Figure 10 (a)). Each sample was placed into the reverse vending machine continuously by eight users (Figure 10 (b)). Once again, the system took a new set of 400 samples.

2.3.4 Processing time

The main issue for user acceptance is the processing time of the machine. In this experiment, the processing time was started when the container was inserted into the machine, and ended when it was successfully classified. There were 10 samples of bottles or cans for each size, for a total of 80 samples, which were fed to the system randomly. The average time was then calculated.

2.3.5 System status

The status of the system was also considered an important feature, and it was sent via the internet at any time to the users as a notification. In this study, the line application was chosen because it was considered a popular application among users. The experimental design was based on the aforementioned experiments.

3. RESULTS

3.1 Performance of classification: color sensor

In this experiment, we focused on setting up a color threshold and evaluating the performance of the color sensor. Once again, the expectation of the system was set to accept the clear plastic bottles and reject other cases. The experimental results are presented in the box plot shown in Figure 6. Hence, the threshold value should be set at approximately 150-200 of the color light intensity, which allows the system to clearly distinguish opaque containers from clear containers. Note that various sizes of clear and opaque containers were tested by inserting the containers into the machine randomly. When each container is categorized as clear, it is pushed to the right and then dropped into the pit and the extruder (Figure 7 (a)), and the result is displayed on the LCD screen (Figure 7 (b)).

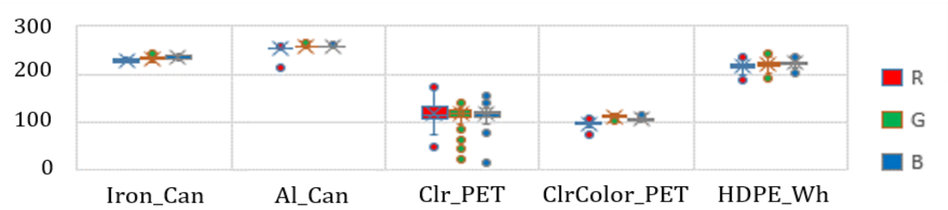


Figure 6. RGB color value distribution of each type of container

Table 3. Results for using the color sensor

	Expectation	Samples	Accuracy	Percentage
Clear plastic bottle (S)	accept	50	50	100
Clear plastic bottle (M)	accept	50	50	100
Clear plastic bottle (L)	accept	50	50	100
Aluminum can (S)	reject	50	50	100
Aluminum can (L)	reject	50	50	100
Iron can	reject	50	50	100
Opaque	reject	50	50	100
Clear colored bottle	reject	50	36	72
Average		50	48.25	96.5

Table 3 shows the classification results of the machine using a color sensor. It was clear that the classification of clear plastic bottles and opaque containers was 100% accurate. For the classification results of clear colored containers, 14 errors occurred in the test. In other words, 14 clear colored containers were judged to be clear plastic bottles. The reason is now being explained. In Figure 6, it can be seen that the color light intensity of the clear plastic bottle was significantly different compared with that of the aluminum can, the iron can, and the HDPE bottle. However, when it was compared with the clear colored container, there was an overlap between the two types.

3.2 Performance of classification: proximity sensor

Figure 8 shows the three signals received from a proximity sensor. The most sensitive inductance was in iron can whereas it was the least objectionable case. Hence, the inductance parameter can be set to the range of the aluminum can. In the test, all sizes of aluminum cans, iron cans, and other containers were tested. Objects were first inserted into the machine one by one in random order. When each object was categorized as aluminum, it was pushed to the left and then dropped into the pit, and the extruder (Figure 9), and the result is displayed on the LCD screen. Table 4 shows the classification results of machines using the proximity sensor that could classify plastic and metal containers with 100% accuracy.

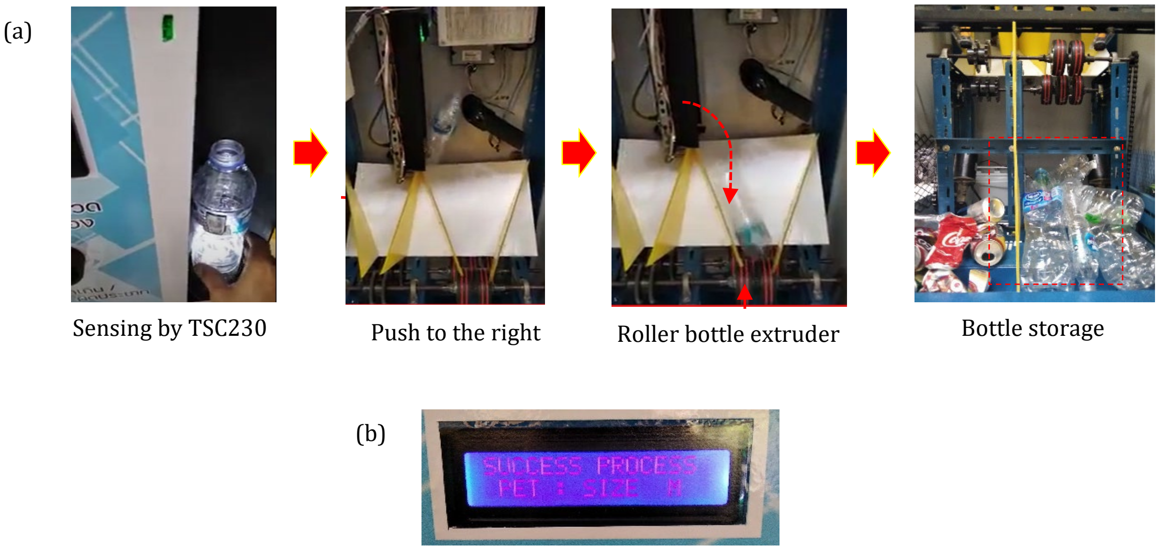


Figure 7. Plastic bottle discrimination using the color sensor. (a) operating steps, and (b) LCD display for detection of a clear plastic bottle

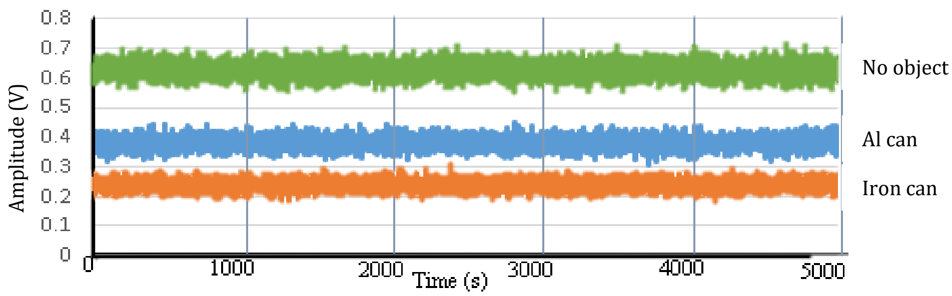


Figure 8. The output signal of iron can, aluminum can, and no object

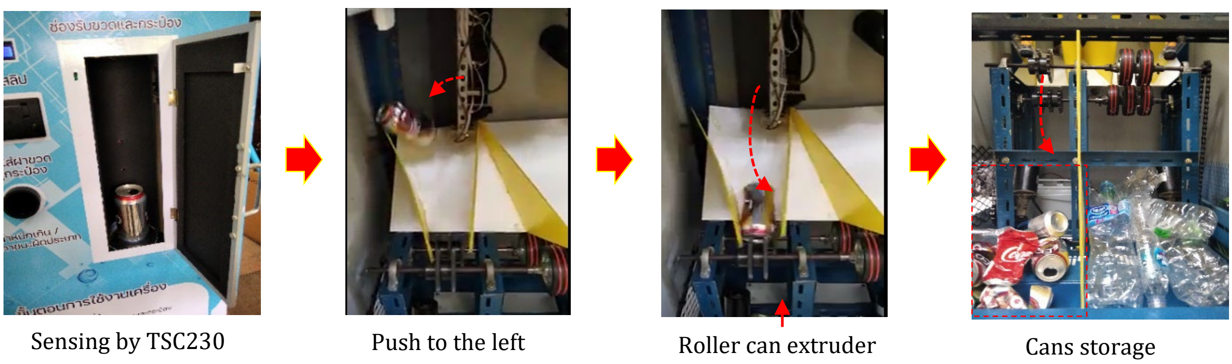


Figure 9. Steps of aluminium can discrimination using the proximity sensor

Table 4. Results for using the proximity sensor

	Expectation	Samples	Accuracy	Percentage
Clear plastic bottle (S)	reject	50	50	100
Clear plastic bottle (M)	reject	50	50	100
Clear plastic bottle (L)	reject	50	50	100
Aluminum can (S)	accept	50	50	100
Aluminum can (L)	accept	50	50	100
Iron can	reject	50	50	100
Opaque	reject	50	50	100
Clear colored bottle	reject	50	50	100
Average		50	50	100

3.3 Performance of classification: color and proximity sensors

In this part, the classification efficiency of color and proximity sensors was investigated. The proximity sensor was used to classify aluminum cans, and the color sensor was used to classify clear plastic bottles. The results of the test are presented in Table 5. The three best results were the aluminum can, the iron can, and the opaque bottle, with 100% accuracy. In the case of the clear colored container, the result was better compared with that of the first experiment. Specifically, out of 50 samples, 10 were classified as clear plastic bottles. The last case that we are going to explain here is the case of the clear plastic container. The results of all sizes were slightly dropped. It could be explained that the cause of the lower result was an effect of light intensity. As mentioned in the previous section, this experiment involved the use of the machine in real location, as shown in Figure 10. So, the light intensity differed from the laboratory set up.

Table 5. Classification efficiency results of the color and proximity sensors for each type of sample

	Expectation	Samples	Accuracy	Percentage
Clear plastic bottle (S)	accept	50	47	94
Clear plastic bottle (M)	accept	50	45	90
Clear plastic bottle (L)	accept	50	49	98
Aluminum can (S)	accept	50	50	100
Aluminum can (L)	accept	50	50	100
Iron can	reject	50	50	100
Opaque	reject	50	50	100
Clear colored bottle	reject	50	40	80
Average		50	47.63	95.25

3.4 Processing time results

The results of processing time are presented in Table 6. The average time for all types and sizes was 5.52 s. The determinated processing time to complete the first step where the type (aluminum or iron) and the size of container (S or L) were 5.13 s, 5.15 s, 5.13 s, and 5.14 s on average. If the determinated object was determined to be not the aluminum containers, the system would do the second step to check for clear plastic bottles, which includes the sizes and transparency. The processing time for this step was 5.75 s on average.

Table 6. Processing time for classifying bottles and cans

	Number of samples	Processing time (s)
Clear plastic bottle (S)	10	5.74
Clear plastic bottle (M)	10	5.76
Clear plastic bottle (L)	10	5.75
Aluminum can (S)	10	5.13
Aluminum can (L)	10	5.15
Iron can	10	5.13
Opaque	10	5.73
Clear colored bottle	10	5.77
Average		5.52
S.D.		0.32

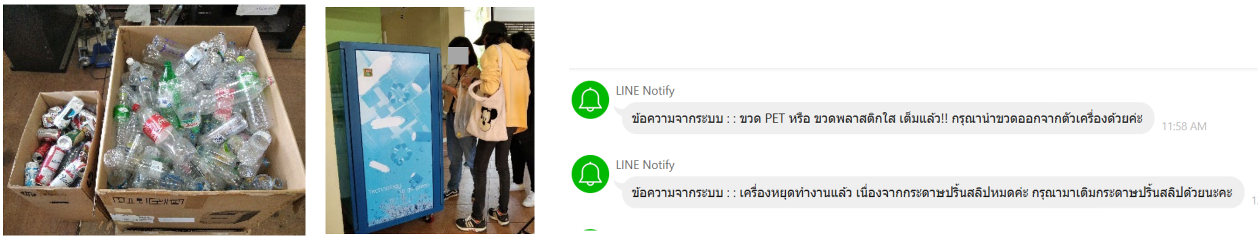
3.5 Result of system status

There are two status notifications: full storage and out of paper status. In maintaining full storage status, if one of the two storages is full, a notification will be sent to the system user, which is the same way for the out of paper status. Figure 10 (c) shows the results with two Thai messages. The first message in the Thai script means "PET or clear plastic bottle storage is full, and please remove the bottles from the machine." The next message means "The machine has stopped working because it is out of paper and please add the printing paper." We found that the feature had operated without errors since the conduct of the previous experiments, which implied that the feature functioned well.

4. DISCUSSION

For accuracy of classification, three experiments were conducted using the color sensor, the proximity sensor, and the combination of both sensors. It is worth noting that the first and second experiments were conducted in the laboratory, where light was controlled. The experimental results showed that the proximity sensor was the best for discriminating between aluminum and iron bottles with 100% accuracy. The second best was the color sensor, which gave 96.88% accuracy. For the third experiment, two sensors were used, and the results were significantly lower compared with the results of the proximity sensor. However, the results were not significantly different, when compared with the results of the color sensor. The first point could be further explained by the fact that some bottle manufacturers add colors to their clear plastic bottles (Caliendo, 2015), resulting in an error of classification. It is worth noting that our results are in accordance with that of a previous study (Oktivasari and Ramadhan, 2018).

For the user acceptance, the experiment was conducted to make sure that the machine was adequate for deployment in the community; the processing time of the machine was investigated. The average time was 5.52 s, which is enough for user acceptance. To increase user acceptance, one feature was added to the system: notification status via the line application. Although we did not conduct an experiment for this feature, no error has been encountered since the machine has been operated. A point of concern is that the users need to manually open the door of the machine, place their containers in the slot, and close the door every time. This inconvenience may be unsatisfactory for some users. However, the acceptance issue needs more investigation, which can be tackled in further studies.



(a) (b) (c)

Figure 10. Experiment in real location; (a) type of samples, (b) the working process, and (c) the trial results of status notification via Line application

5. CONCLUSIONS

The reverse vending machine was successfully developed. As an economical product, low-cost sensors (color sensor and the proximity sensor) were chosen. The developed prototype works well for identifying beverage containers, including plastic bottles and aluminum cans. The efficiency of the classification showed excellent results. In addition, the machine was operated in real-time and functioned without any bar codes or databases. One of the advantages of our design is that it can accommodate a wide variety of containers, as the system accepts up to three sizes. The machine can correctly operate over the long term as long as the container materials are made of plastic or aluminum.

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