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# Developing barcode scan system of a small-scaled reverse vending machine to sorting waste of beverage containers

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**ABSTRACT**

Reduce, Reuse, and Recycle is a campaign which aims to reduce the production of waste. Industry used plastic bottle and cans to store the beverage. A research was done by University of Georgia, United States and was published by Wall Street Journal stated that Indonesia is the second predicate country which produced and mismanaged plastic waste in the world. This condition shoud be overcome and this research project was intended to develop reverse vending machine (RVM) to sorting waste of beverage containers either plastic bottles or cans as a campaign to reduce the production of waste. This RVM machine uses barcode scanning as the sorting system to determine whether the plastic bottle or can could be recycled or not. In order to check the weight of the beverage container, a load cell sensor is used to check whether the beverage container is empty or not. The machine will receive the container from the conveyor station, check the weight, and finally transfer it to the sorting station. The container will be sorted as cans or plastic bottle by the aid of barcode scanning and compare it to database. Furthermore, the plastic bottle will be sorted as clear or colored plastic bottle. Unrecyclable plastic or can container or any unemptied container will be classified as rejected container and be returned to the user through the outlet passage. The performance testing was done with 12 different types of plastic bottle and can and 10 samples for each type, so there were total 120 items tested and the result showed that the success rate was 94% while the processing time was varying in between 8 to 13 seconds.



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## 1. INTRODUCTION

Many products are made of plastics, since they are cheap, light and long-lasting. However they are not easily decomposed by nature, so to reduce the plastics waste, they can be sorting and recycled. Beverage industries require containers to store the beverage and most of them are not reusable [1-9]. One of the methods to reduce beverage containers in bins is the implementation of reverse vending machine (RVM). It is a machine which sorts and collects beverage containers (glass bottles, plastic bottles and cans) and crushed them to minimize the size and gives some money to the user in return.

Swiss German University (SGU) has developed barcode scan system of a small-scaled reverse vending machine to accept not only plastic bottles, but also cans [10, 11]. It consists of three stations such:

a weight station, roller station and sorting station as shown in Figure 1 system overview of the RVM. A database of commercial beverages will also be implemented as the reference. It may also store the activity log of the day. Finally, a LCD and a push button will also be installed.

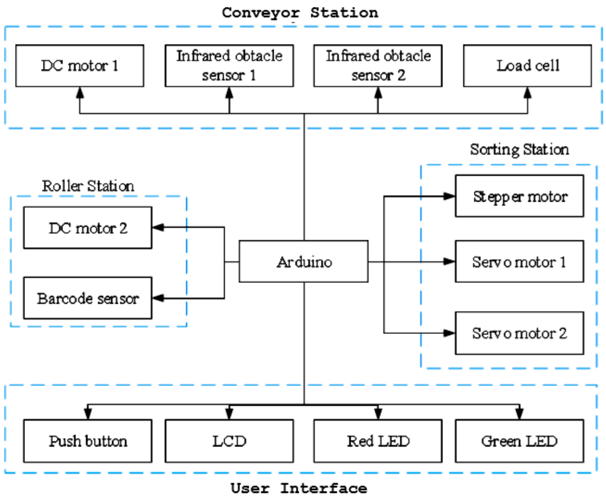


Figure 1. Reverse vending machine (RVM) system overview

## 2. RESEARCH METHOD

### 2.1. Mathematical model to find the required slope for roller station

One of the important parts in designing the RVM system is the design of roller station's slope. A mathematical model is implemented to find the minimum angle for the roller and also to determine the behaviour of the roller station and what factors affect its performance. We would like to overcome friction by the help of gravitational force and at the same time to maintain a constant speed going down the roller. The bottle goes to the roller station with a speed of $V_{in}$ as shown in Figure 2, which is directly proportional to the speed of the conveyor. The x-axis is the base of the roller, while the y-axis is the normal axis towards the base of the roller. The arrow indicates the positive sign for the axis. Figure 3 shows the free body diagram of the bottle when above the roller station.

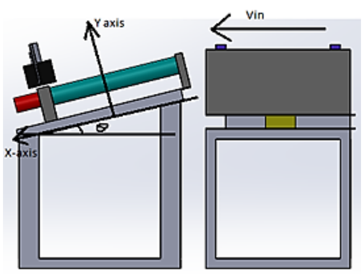


Figure 2. Roller and conveyor station

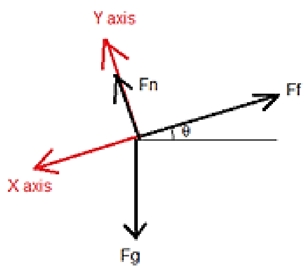


Figure 3. FBD of bottle on roller station

$F_f$ is the frictional force, while $F_g$ is the gravitational force. $F_{gx}$ is the gravitational force in x-axis, while $F_{gy}$ is the gravitational force in y-axis. In order to make it balance, $F_f$ should be equal to $F_{gx}$. $F_{gx}$ is defined as (1);

$$F_{gx} = F_g \times sin\theta \quad (1)$$

while the $F_f$ is define as normal force (equivalent to $F_{gy}$) multiplied by the friction coefficient *($\mu$)*. The $F_{gy}$ is defined as $F_g$ multiply with *$cos\theta$*. Hence $F_f$ is defined as (2).

$$F_f = F_g \times cos\theta \times \mu \quad (2)$$

since we would like to make it balance too, $F_{gx}$ is equal to $F_f$. The $F_g$ can finally be crossed out and left with *sinθ* equals to *cosθ* multiplied by $\mu$. Moving *cosθ* to left hand side result in *tanθ*. So, *the angle, θ* can be defined as (3);

$$\theta = \tan^{-1}\mu \tag{3}$$

We do not know the value of the friction coefficient then the angle for the roller station is obtained by trial and error experiment. The friction coefficient depends on the surface of the roller and surface of the container and the speed of the sliding can also be defined as (4):

$$Vslide = Vin \times cos\theta \tag{4}$$

The equivalent force in y-direction should be zero, and in the equivalent force in x direction should also be zero as shown in (5) and (6);

$$\begin{gathered} \Sigma F_y = 0 \\ F_{gy} = F_{normal} \\ F_{normal} = F_{gy} = F_g \times \cos\theta \end{gathered} \tag{5}$$

$$\begin{gathered} \Sigma F_x = 0 \\ F_{gx} = F_{friction} \\ F_{friction} = F_{normal} \times \mu \\ F_g \times \sin\theta = F_g \times \cos\theta \times \mu \\ \theta = \tan^{-1}\mu \end{gathered} \tag{6}$$

In order to get the friction coefficient, so we do it empirically. The roller is supplied with 9V voltage source, then the end of the roller is lifted slowly and the height in which the beverage container starts to slide will then be recorded. Ten samples were used and ten experiments were conducted per sample. The results are shown in Table 1.

Table 1. Roller angle testing

| No | Bottle Type | Average Elevated Height (cm) | Roller Angle (degree) |
|---|---|---|---|
| 1 | Root Beer | 4.01 ± 0.19 | 6.77 |
| 2 | Bird Nest | 3.91 ± 0.14 | 6.6 |
| 3 | Cap Kaki Tiga | 4.01 ± 0.14 | 6.77 |
| 4 | Coca Cola | 4.60 ± 0.12 | 7.78 |
| 5 | Floridina | 4.19 ± 0.14 | 7.08 |
| 6 | Sprite | 4.50 ± 0.18 | 7.61 |
| 7 | Mizone | 4.32 ± 0.15 | 7.3 |
| 8 | Aqua | 4.88 ± 0.15 | 8.25 |
| 9 | Le Minerale | 4.85 ± 0.14 | 8.2 |

### 2.2. Required speed for beverage container

There are two calculation needed, the rotational and translational speed. The scanning rate of the barcode scanner (Motorola LS 9208) is 40 ms, the effective scanning area is 10 cm in diameter, and the average diameter of bottle is 6.5 cm, while the diameter of the roller is 4 cm. The smallest barcode height is 7 mm and the length is 20 mm. The linear speed in roller and beverage container is the same, as illustrated in Figure 4, however they are opposite direction. The maximum rotational speed is the barcode height (7 mm) divided by the barcode scanning rate (40ms) which equals to 17.5 cm/s. The period of the roller is 60 min divided by 84 rpm, which is equal to 0.71 s. The velocity of the roller is circumstance of the roller divided by the period of the roller (0.71 s) which equals to 17.59 cm/s. Hence the required speed of the beverage container is equal to 17.59 cm/s. The speed is higher a bit but it is fine since there are some slips on the roller. The period for one rotation of the beverage container is defined as the circumstance of the beverage container divided by the roller speed (17.59 cm/s) which is 1.16 s. The period will then be used in translational speed calculation. The maximum theoretical translational speed is defined as barcode length (20 mm) divided by the period (1.16 s) which equals to 1.72 cm/s. While the real velocity based on calculation is approximately 14 cm/s, based on conveyor motor specs. However, we do not model the housing of the roller, since in reality it damps the beverage container initial velocity.

### 2.3. Stepper motor torque requirement

This is the calculation done for the stepper motor used in the roller station. It may rotate clockwise (bottle accepted) or counter-clockwise (bottle rejected). The bottle located on the middle of the kicker. Figure 5 shows the illustration. The stepper motor should overcome the torque produced by the kicker and the bottle itself. While torque is defined as force multiply with perpendicular distance between the force and the pivot point (r). For this case the force is coming from the friction and the friction is resulted from normal force multiply with the friction coefficient (μ). Let us just use static because it is bigger than sliding. Eventually normal force is coming from the weight of the object. Hence torque equation for kicker and bottle can be defined as;

$$\tau_{motor} = \tau_{kicker} + \tau_{bottle} \quad (7)$$

$$\tau = m \times g \times \mu \times r \quad (8)$$

For simplicity, let us assume the friction coefficient of kicker and bottle is the same. Furthermore, let also assume that $r$ is the same, we will take the maximum, which is the length of the kicker. Hence the torque of the motor can be simplified to (9).

$$\tau_{motor} = g \times \mu \times r \times (m_{kicker} + m_{bottle}) \quad (9)$$

Let us assume that: $g$ = 9.81 m/s2, $\mu$ = 1 and r = 0.2 m, mass of kicker is 200 gr, and mass of bottle is 50 gr. The friction coefficient is taken from the average value in particular website. The ***r*** is the length of the kicker, we obtain the required torque is 0.4905 Nm.

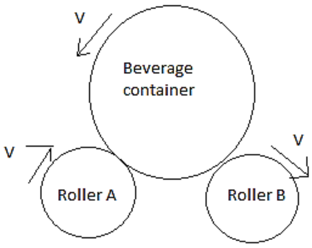


Figure 4. Rotational motion model of roller station

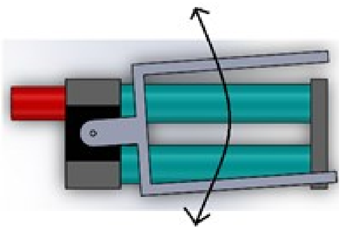

Figure 5. Design of stepper motor in roller

### 2.4. Mechanical design using Solidworks

Based on the mechanical design point of view, the RVM consist of several machine sub systems, material, dimension, and the related critical aspects [12, 13]. The 3D model of RVM can be seen in Figure 6 and Figure 7. Conveyor station consists of linear conveyor, two infrared obstacle sensors and a 24 V DC motor. The weight measurement system is placed below the linear conveyor. It is made up of two metal plates which have a thickness of 2 mm. The roller station consists of the roller and the Omni barcode scanner. The roller station has a dimension of 100x70x300 mm. The sorting station consists of stepper motor, two servo motors, and a support structure. The support structure is also used by the roller station [14-17]. The dimension of the support structure is 110x320x340 mm. Three storage-containers were made to store the sorted beverage container; they are clear plastic bottle, color plastic bottle, and cans. The reject plane has a dimension of 150x250x50 mm.

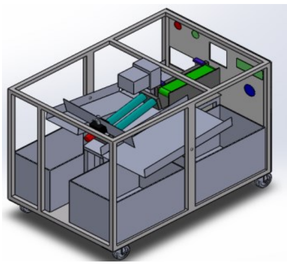

Figure 6. Main frame mechanical design

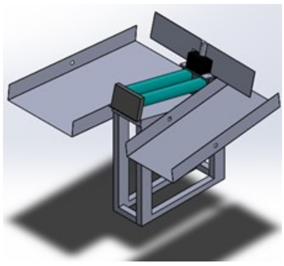

Figure 7. Sorting station design using Solidworks

### 2.5. Program design of reverse vending machine

In order to run the RVM, a flowchart was design and then we developed the program using Arduino IDE software. The whole logical processes from the initialization, sorting system and data recording of total plastic bottles and cans processed can be seen in Figure 8.

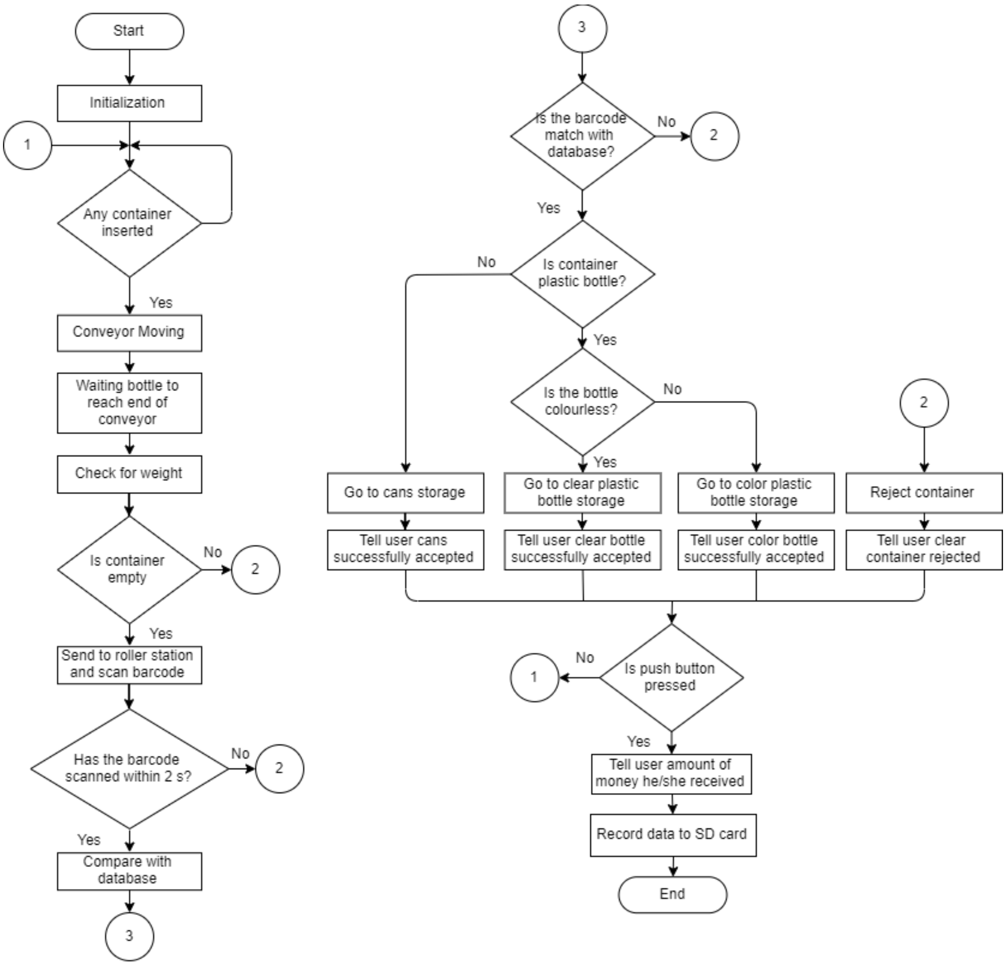


Figure 8. Flowchart of RVM program design

## 3. RESULTS AND ANALYSIS

### 3.1. Omnidirectional barcode scanner performance testing and analysis

Barcode Scanner, Motorola LS 9208 is the omnidirectional barcode scanner is used in this research project [18, 19]. Firstly, we need to test the scanning distance and the barcode scanner orientation. This test was crucial as the barcode scanner could be said the main sensor use in this research. It was used to scan the entire incoming container's barcode. Every beverage container has different size, barcode location, and barcode quality. Hence these tests were required. The result is shown in Table 2.

From the result shown in Table 2, we can see that the optimum sensing distance is until 10 cm. The barcode dimension really affects the performance of the scanning process. Moreover, the barcode orientation is effect too. Barcode Reader scans horizontal barcode orientation however it has some difficulty to scan vertical barcode. Hence to solve this problem the barcode should be tilted 45 degree.

### 3.2. Load cell testing and analysis

The tests were conducted by using sample copper masses. The copper masses are 10 g, 20 g, 50 g, 100 g, and 200 g. The container weight less than 50 g, hence this weight range is chosen. The weight cell will later be used to detect filled container and reject them. This test also carried to set the scale of the weight to get accurate weight measurement. The result of the load cell performance is shown in Table 3 [20, 21]. Another test as shown in Table 4 was conducted by using twelve (12) types of beverage containers. The actual mass is measured using device with a 0.1-gram precision. The average mass was taken from

30 samples. The result shows that the deviation error is varrying in between 0.87% until 26.67%. Eventhough the error is quite big, but it is still acceptable due to the small mass of beverage containers and the set point (empty container) of container's mass was adjusted to 30 gr.

Table 2. Barcode scanner testing

| No | Beverage Container | Type | Sensor Distance Detection | | | | Barcode Dimension mmxmm |
|---|---|---|---|---|---|---|---|
| | | | 5 cm | 10 cm | 15 cm | 20 cm | |
| 1 | Le Minerale | Clear Bottle | Yes | Yes | No | No | 25x10 |
| 2 | Stee | Clear Bottle | Yes | Yes | No | No | 20x11 |
| 3 | Indomaret Water | Clear Bottle | Yes | Yes | Yes | No | 24x11 |
| 4 | Floridina | Clear Bottle | Yes | Yes | No | No | 24x8 |
| 5 | Kopiko | Clear Bottle | Yes | Yes | Yes | No | 24x10 |
| 6 | Coca Cola | Clear Bottle | Yes | Yes | Yes | No | 19x8 |
| 7 | Sprite | Color Bottle | Yes | Yes | Yes | No | 21x9 |
| 8 | Mizone | Color Bottle | Yes | Yes | Yes | Yes | 30x10 |
| 9 | Bird Nest | Can | Yes | Yes | Yes | Yes | 25x13 |
| 10 | Green Sands | Can | Yes | Yes | Yes | No | 20x11 |
| 11 | Cap Kaki Tiga | Can | Yes | Yes | Yes | No | 22x11 |
| 12 | Root Beer | Can | Yes | Yes | Yes | No | 25x7 |

Table 3. General load cell testing

| No. of Trial | Load-Mass (gram) | | | | |
|---|---|---|---|---|---|
| | 10 | 20 | 50 | 100 | 200 |
| 1 | 10.71 | 19.78 | 49.24 | 99.13 | 200.03 |
| 2 | 10.53 | 20.2 | 49.03 | 99.21 | 199.03 |
| 3 | 11.22 | 19.45 | 48.89 | 99.34 | 198.36 |
| 4 | 10.35 | 19.73 | 49.22 | 98.78 | 198.66 |
| 5 | 9.22 | 19.8 | 49.11 | 10.66 | 198.67 |
| Avg. | 10.41 ± 0.74 | 19.79 ± 0.27 | 49.10 ± 0.14 | 99.42 ± 0.72 | 198.95 ± 0.65 |

Table 4. Load cell testing of containers

| No. | Beverage Container | Actual Mass* (gram) | Load Cell Mass, 30 samples (gram) | Error (%) |
|---|---|---|---|---|
| 1 | Le Minerale | 19.80 | 20.83 | 5.20 |
| 2 | Stee | 24.40 | 24.64 | 0.98 |
| 3 | Mizone | 25.70 | 26.72 | 3.93 |
| 4 | Floridina | 22.90 | 22.70 | 0.87 |
| 5 | Kopiko | 21.30 | 20.74 | 2.63 |
| 6 | Coca Cola | 22.40 | 21.85 | 2.46 |
| 7 | Green Sands | 12.60 | 9.24 | 26.67 |
| 8 | Cap Kaki Tiga | 12.70 | 9.83 | 22.60 |
| 9 | Bird Nest | 14.90 | 13.15 | 11.74 |
| 10 | Indomaret Water | 16.30 | 17.35 | 6.44 |
| 11 | Sprite | 22.00 | 22.60 | 2.73 |
| 12 | Root Beer | 13.70 | 14.47 | 5.62 |

### 3.3. DC-motor testing and analysis

There are two DC motors used in this research project, both are 24V rated. Both have come with a gearbox. DC motors testing need to be carried out to check the performance of the DC motors. This test was conducted by giving various voltages to the DC motor. The test was conducted with input voltage range from 0V to 24V with an increment of 2V. The input voltage was controlled by DC-DC converter, LM 2596 [22-26]. The flowing current and rotational speeds were then measured. The current was measured with FLUKE 87, while the rotational speed was measured with a digital tachometer DT-2234C+. To measure the angular speed, a reflective strap is attached to rotating part.

The first DC motor tested was the linear conveyor motor, Table 5 (a). The reflective strap was attached to the conveyor belt. The rotational speed shown in Table 5 was the average of three readings. The startup voltage of the motor is found out to be 5.8V with a current of 0.244.A. Please take note that the current before the startup is high (2V and 4V). After the motors run, the current was more or less constant. The second DC motor tested was the linear conveyor motor, Table 5 (b). The reflective strap was attached to the roller. However, a black tape was attached before the reflective strap. This is due the surface of the roller is reflective (a transparent tape covers it).

### 3.4. RVM full system testing and analysis

This preliminary full system testing was done after all the mechanical and electrical parts assembled; the machine runs full system testing. Various container types were inserted (clear bottle, color bottle, and cans). Various conditions also tested (empty or filled container). The test was carried out with 12 beverage containers. The result is shown in Table 6. From the preliminary full testing, the "Weight read < 30 grams" column shows weather the weight measured is smaller than 30 grams or not, while the "Barcode scanned:" column tells whether the barcode scanner successfully read the barcode or not. From 20 trials, the overall successful rate the RVM machine was ± 80%. The failures came sometimes from the barcode miss the scanning area and the SD card reader.

The second full system testing using Arduino Uno attached to the barcode scanner. The result is more reliable. Twelve types of beverage containers were used and ten samples will be tested per type. From this final testing, the average successful rate was 94.17%. There were three kinds of problems occur during the test, they are: load cell fails to detect, barcode not recognized, and mechanical problem. The time cycle of the machine is shown in Table 7. From Table 8 processing time was varying between 8 to 10 seconds. Rejected due to the overweight was only 4-5 seconds. It took longer time when the bottle rejected due to the unrecognized barcode code.

Table 5. Conveyor motor testing for both DC motors; (a) linear conveyor, (b) roller conveyor

| (a) Linear conveyor | | | (b) Roller conveyor | | |
|---|---|---|---|---|---|
| Voltage (V) | Current (A) | Speed (rpm) | Voltage (V) | Current (A) | Speed (rpm) |
| 0 | 0.000 | 0.0 | 0 | 0.000 | 0.0 |
| 2 | 0.071 | 0.0 | 2 | 0.135 | 15.1 |
| 4 | 0.151 | 0.0 | 4 | 0.159 | 34.3 |
| 6 | 0.111 | 8.2 | 6 | 0.173 | 57.4 |
| 8 | 0.113 | 12.0 | 8 | 0.175 | 73.6 |
| 10 | 0.115 | 15.8 | 10 | 0.186 | 94.3 |
| 12 | 0.116 | 19.4 | 12 | 0.207 | 113.8 |
| 14 | 0.111 | 23.1 | 14 | 0.205 | 132.2 |
| 16 | 0.112 | 27.3 | 16 | 0.227 | 148.3 |
| 18 | 0.113 | 30.8 | 18 | 0.232 | 169.6 |
| 20 | 0.116 | 34.1 | 20 | 0.244 | 189.2 |
| 22 | 0.114 | 37.5 | 22 | 0.267 | 206.9 |
| 24 | 0.115 | 42.9 | 24 | 0.279 | 224.5 |

Table 6. Preliminary full testing RVM

| Trial No. | Container Inserted | Real Condition | Weight Read < 30gram | Weight Remark | Barcode Scanned | Type Determined | Type Remarks |
|---|---|---|---|---|---|---|---|
| 1 | Indoma | Clear, | Yes | Success | Success | Clear | Success |
| 2 | Cap | Can, | Yes | Success | Success | Can | Success |
| 3 | Sprite | Color, | Yes | Success | Success | Color | Success |
| 4 | Mizone | Color, | Yes | Success | Success | Color | Success |
| 5 | Aqua | Clear, | Yes | Success | Success | Clear | Success |
| 6 | Le | Clear, | No | Success | x | x | x |
| 7 | Indoma | Clear, | Yes | Success | Success | Clear | Success |
| 8 | Le | Clear, | Yes | Success | Success | Clear | Success |
| 9 | Bird | Can, | Yes | Success | Success | Can | Success |
| 10 | Floridi | Clear, | Yes | Success | Fail | x | x |
| 11 | Floridi | Clear, | Yes | Success | Success | Clear | Success |
| 12 | Aqua | Clear, | No | Success | x | x | x |

Table 7. Result of final full system testing

| No | Beverage Container | Percentage of Success (10 samples) | Remark of Insert Position |
|---|---|---|---|
| 1 | Le Minerale, Clear | 75 | Bottom |
| 2 | Stee, Clear | 90 | Bottom |
| 3 | Mizone, Color | 90 | Bottom |
| 4 | Floridina, Clear | 90 | Bottom |
| 5 | Kopiko, Clear | 100 | Bottom |
| 6 | Coca Cola, Clear | 100 | Top |
| 7 | Green Sands, Can | 100 | Top |
| 8 | Cap Kaki TIga, Can | 100 | Top |
| 9 | Bird Nest, Can | 100 | Bottom |
| 10 | Indomaret Water, Clear | 100 | Top |
| 11 | Sprite, Color | 90 | Top |
| 12 | Root Beer, Can | 100 | Bottom |

Table 8. Result of machine's processing time

| No | Processing Cycle | Processing Time (Sec) |
|---|---|---|
| 1 | Accepted Beverage Container (Clear or Color Bottle and Cans) | 8 - 10 |
| 2 | Rejected Bootleg due to Overweight | 4 - 5 |
| 3 | Rejected Bottle due to Barcode Unrecognized | 12 - 13 |

## 4. CONCLUSION

The small-scaled RVM machine was successfully developed and able to detect and to differentiate clear bottle, color bottle, and cans. Moreover the machine is also expected to differentiate empty and filled container, this is achieved through load cell. The program development was also successfully designed to make the system works together harmoniously. It is able to make the barcode scanner works, accurate weight measurement from the load cell, correct sensors reading, and make actuators working. Moreover the data logging and user interface is also working correctly according to the flowchart.

The overall successful rate based on the full testing was 94.17% and the processing time was in between 8 to 13 seconds, this result is fulfill the expectation. In the future the RVM prototype can be implemented in our daily life, to reduce the waste of plastic bottle and cans. Further recommendation to improve the machine by combining the weight station and roller station into one station, to reduce the processing time, and possibility to use camera vision with mini PC to the replace the barcode reader and microcontroller board.

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