Designing and Developing a Plastic Bottle Shredding Device with an RFID-Based Waste Management System at Jakarta Global University Campus

Meishin Arlince*,a,1, Ariep Jaenul a,2, Arisa Olivia Putri a,3
[a]Universitas Global Jakarta, Depok, Indonesia

*Corresponding Author: meishinarlince@student.ac.id

Abstract

This study investigates the measurement of plastic waste, commonly found in public areas such as the Global University of Jakarta campus, using both manual and automated weighing systems. This research aims to compare the accuracy of a manual scale and an automated load cell system, with a monetary conversion of 1 gram equating to IDR.3. This research employs a Research and Development (R&D) design where experimental tests were conducted to measure plastic waste weight with both systems. The first test revealed a weight range of 6.5–9.5 grams using the load cell, compared to 6.7–9.7 grams on the manual scale. The second test showed a range of 16.5–21.1 grams for both systems, while the third test showed 31.8–36.3 grams on the load cell and 32–36.8 grams on the manual scale. The error margin between the two systems remained below 3%, indicating a high level of accuracy in the automated system. The findings demonstrate that the automated system reliably approximates manual measurements, with each gram of plastic waste valued at IDR.3. To enhance the system's performance, future research should focus on incorporating a specialized cutting mechanism for plastic bottles to reduce vibrations, optimizing load cell placement for precision, and constructing the prototype from durable materials such as stainless steel to ensure both safety and measurement accuracy. These improvements could further advance the system's efficacy in plastic waste management.

Keywords: Plastic Bottle Waste, RFID, DC Motor, Load Cell

I. Introduction

Waste is an important problem that almost occurs all over the world and has not been solved properly, especially in Indonesia[1]The types of waste produced from various human activities can be categorized into organic, inorganic, and metal waste[2]. However, among these types of waste, plastic waste is a major concern because of its nature which is difficult to decompose naturally, taking up to hundreds of years to degrade completely[3]. Based on data revealed by *Prof. Enri Damanhuri*, an expert in Air and Waste Management from the Bandung Institute of Technology (ITB), in a 2021 Fitriani article, Indonesia produces around 5.4 million tons of household waste yearly [4]. Of this amount, 14% is plastic waste. This makes Indonesia the country with the second-largest amount of household waste in the world. This dominant plastic waste does not only come from household activities, but also from various other sectors such as offices, trade, the education sector, and the tourism sector[5].

Single-used plastics, such as beverage bottles, bottle caps, and shampoo bottles, are the main contributors to this plastic waste. Data from 2019 shows that plastic consumption in Indonesia reaches 5.6 million tons annually, most of which comes from packaging products[6]. Plastic waste from this packaging is often not treated properly, causing piles of plastic waste to pile up in landfills (TPA) and the surrounding environment, polluting the ecosystem and threatening the lives of living things, especially in marine areas[7]. The problem of plastic waste is a serious challenge for Indonesia. Effective solutions in reducing plastic consumption as well as processing and recycling efforts are urgently needed. Increasing public awareness and implementing more efficient waste management technologies are important steps to reduce the adverse impact of plastic waste in the future [8].

Based on the results of mandatory research, plastic bottle waste is often scattered in public places, especially in campus areas [9]. This shows that although environmental awareness is starting to increase, there are still many who are not disciplined in disposing of waste in its place, especially plastic bottles [10]. Plastic bottles are one of the most widely found types of waste because of their very wide use, both as beverage packaging, cleaning products, and daily necessities [11]. This condition provides an important responsibility for the campus to find innovative solutions in dealing with environmental problems, especially in the management of plastic bottle waste. Systematic efforts and adequate technology are needed to reduce the volume of plastic waste that accumulates in the campus environment[12].

In this case, innovation in plastic bottle waste processing equipment is very important [13]. The tool must be able to minimize the size of plastic bottle waste through the right process, such as compaction or shredding, so that the space in the bin can be maximized [14]Thus, the garbage collection is not filled quickly, and the campus environment is kept clean [15]. The use of this kind of tool can also support recycling efforts more easily, as plastic bottle waste has been processed into smaller sizes and is easier to manage [16]. This innovation is expected to be the first step in creating a cleaner and environmentally friendly campus, as well as increasing the awareness of the entire academic community on the importance of maintaining environmental cleanliness[17].

The research carried out is the development of the previous research and a study is made with the title "Design and Build a Plastic Bottle Waste Shredder with an RFID-Based Waste Management System on the Campus of the Global University of Jakarta", in this study using DC motor components to move the blade, to cut plastic bottle waste and can minimize space in the trash can[18]. In addition, this system uses RFID components so that students can access it by using a registered ID card to provide rewards in the form of cash balances[19]. This system can improve campus cleanliness and reduce the amount of plastic bottle waste that is scattered. The application of this technology is an alternative in efforts to innovate environmental cleanliness in the campus area of Universitas Global Jakarta. Therefore, this research aims to compare the accuracy of a manual scale and an automated load cell system, with a monetary conversion of 1 gram equating to IDR.3

II. METHOD

In this study, the research and development (R&D) method was used to develop a prototype to improve the cleanliness of the campus area of the Global University of Jakarta[20]. Research and development method is a "bridge" between basic research and applied research, where basic research aims to "find new information about basic phenomena" and practical applied research. Although there is also applied research to developing products. The purpose of research and development is product discovery, development, and validation.

Furthermore, the researchers reviewed several literatures that discussed the same topic of problems. After researching various literature, the researcher tried to design components that would be used to improve the cleanliness that had been formulated. After the component was designed, the researcher programmed the controller on the component that had been designed. It was intended so that the designed component could run as the researcher wanted. After programming, the researcher conducted a test on the prototype that had been designed. At the time of the test there were two possibilities occurring, namely whether the prototype was running well or there would be problems. If the prototype had problems, then the researcher would inspect whether there were problems with the prototype component set, or there were problems with the program written or there were problems with both the prototype component series and the program written. After the inspection was carried out, the researcher overcame the problem until the prototype could run well. After finding that the components could run well with the ordered program, the researcher then collected data from the designed components. Researchers collected data from the components that had been designed, with the system responding when running and measuring the weight obtained from the device to enter the RFID balance and testing on the servo motor[21]. After obtaining the data, the researcher analyzed the data to assume the previous data.

A. Hardware Design

The tools used include hardware and software. The hardware included Arduino Uno R3, Power supply, Relay Module, 12inc LCD, RFID Module, Limit switch, DC Motor, Servo motor, Load cell sensor, LED Light, Down Stop Module, RC snubber, AT24Cxx[22][23][24][25].

B. Chassis Design

The manufacture of hardware started with the design of the place to be used, then an Arduino Uno board, RFID modules, LCD, DC switches and motors, servo motors, and load cells are installed. The material used to make the case was a bucket as a container and the manufacturer also used hollow iron as a pole or frame on the tool. The height diameter of the chopping tool was 118cm and the width was about 36cm, for a tubular bucket with a size of 30 x 28 cm and it was given several 5cm holes in it. At the bottom, the second tube used a bucket that was cut to a size of 12 x 27 cm, and the third tube used a bucket with the rest of the second tube with a size of 6 x 27 cm using a funnel on it. In addition to the chopper, the manufacturer used a 22 cm-wide and 31cm-long and a 39 cm-high table.

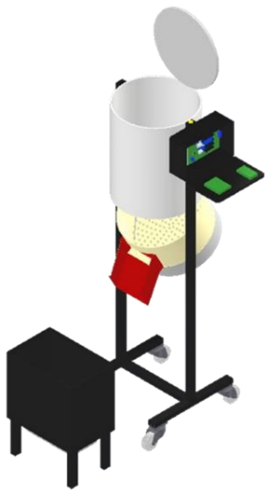

Figure 1 Case Prototype Form

C. Control Circuit

In the series of prototypes, the researcher added a diagram block scheme to provide an overview of the prototype to be designed in this study. The block scheme of the system design diagram can be seen in the following figure.

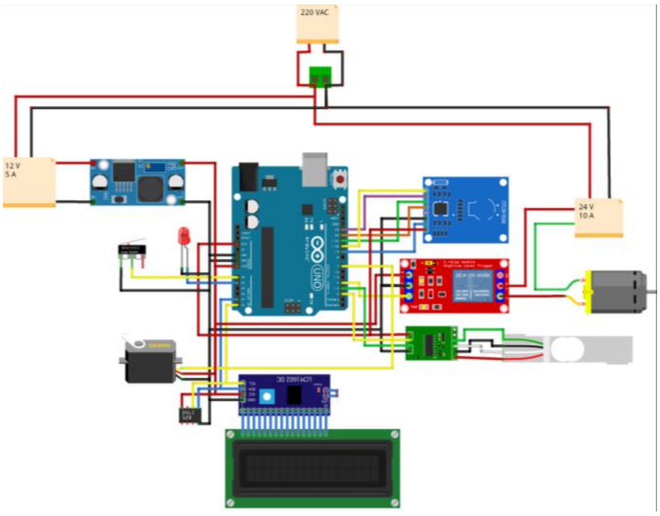

Figure 2 Control Circuit

The Figure above shows the network schematic for the components to be designed. The image also shows the microcontroller used, which is connected to all of these components and serves to process inputs from other components. In addition, the microcontroller also functions to give commands to the actuator to process the data that has been obtained from the input components.

D. Block Circuit Diagram

In the series of prototypes, the researcher added a diagram block scheme to provide an overview of the prototype to be designed in this study. The block scheme of the system design diagram can be seen in the figure next.

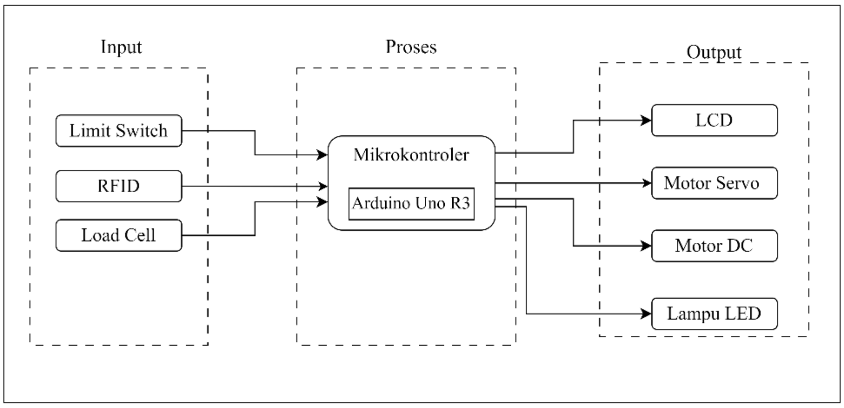

Figure 3 Block Circuit Diagram

The Arduino uno R3 functions as the main microcontroller with all input and output components. Arduino is a control that works to receive input from the input component, the first input process is on the RFID component used to access (run) the tool used by the user. If the RFID does not recognize the ID card, the microcontroller provides a notification to reject in the form of a red LED light. This RFID is also used for registered ID cards because it functions to store the balance of the results from the garbage they dispose of. In the next step, a limit switch is used that will drive the output, namely the DC motor and the last input is a loadcell where this process will weigh the results of the enumeration. After the input is processed by the microcontroller, the microcontroller will give commands in the form of outputs, outputs in the form of DC motors that will rotate the blades while other outputs are on the LCD to display the balance.

III. RESULTS AND DISCUSSION

A. Tools Implementation

The manufacture of hardware started with the design of the place to be used, then an Arduino Uno board, RFID modules, LCD, DC switches and motors, servo motors, and load cells were installed. The material used to make the case was a bucket as a container and the manufacturer used hollow iron as a pole or frame on the tool. The height diameter of the chopping tool was118cm and the width was about 36cm, for a tubular bucket with a size of 30 x 28 cm and it was given several 5cm holes in it. At the bottom, the second tube used a bucket that was cut to a size of 12 x 27cm, and the third tube used a bucket with the rest of the second tube with a size of 6x27 cm using a funnel on it. In addition to the chopper, it uses a 22cm-wide table for 31cm-long and 39 cm-high scales.

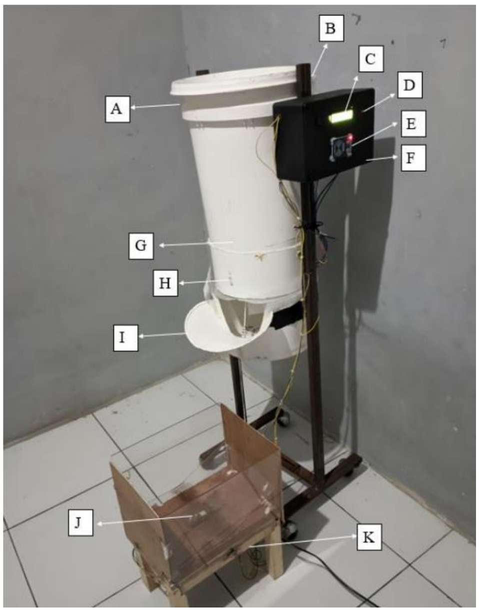

Figure 4 Container

Based on the image above, A prototype has been made. The image also shows six points each component used, they are component A to F. Component A refers to place to place plastic bottle waste that will be chopped, plastic bottles will be put in which will then be chopped by the blade inside. Component B is a limit switch component to drive the DC motor to rotate the blade. Component C is an i2c 16x2 LCD that will display information about the condition of the chopper motor, the weight of the chopper, the balance of the cred, the balance obtained from the result of the dredging of plastic bottles, and the balance of each member. Component D is an LED light used as an indicator of whether the card tapped on the RFID is a member or a non-member, if it is a non-member, this LED will light up. Component E is an RFID module to tap the ID card before enumerating and the second tap after the counting results have been weighed. Component F is a box containing components such as Arduino IDE, relay, power supply, HX711 module, step-down module, RC Snubber, and EAPROM ATC24xx Memory Module.

B. Configuration

In load cell and manual testing, calculations were carried out to see the error value on each object, with a maximum error value tolerance of 10%. To calculate the error value, determine the percentage of success and failure on load cell scales and system manuals, this research and development used the following calculation.

$$error = \left|\frac{Loadcell - manual}{}\right| \times 100\%$$

To get valid results, three tests were carried out using six registered ID cards. The first test used one plastic bottle, the second test used two plastic bottles, and the third test used three plastic bottles. Each test also used a 600ml plastic bottle. Each counting result obtained was weighed using a manual scale to determine the accuracy value of the load cell.

Table 1 Test Analysis on Loadcell

Member	Test 1				Test 2				Test 3				Amount of Balance Earned
	Load Cell (grams)	Manual (grams)	Error %	Balance earned	Load cell (grams)	Manual (grams)	Error %	Balance earned	Load Cell (grams)	Manual (grams)	Error %	Balance earned	
Member 1	9,4	9,5	2%	IDR.27	20,6	20,8	0,9%	IDR.60	34,4	34,8	1,1%	IDR.102	Rp,189
Member 2	6,5	6,7	2,9%	IDR.18	16,3	16,5	1,2%	IDR.48	32,7	32,0	0,6%	IDR.96	IDR.162
Member 3	9,0	9,2	2,1%	IDR.27	21,7	21,9	0,9%	IDR.63	36,3	36,8	1,3%	IDR.108	IDR.198
Member 4	7,6	7,8	2,5%	IDR.21	17,7	17,9	1,1%	IDR.51	34,2	34,6	1,1%	IDR.102	IDR.174
Member 5	9,5	9,7	2%	IDR.27	20,9	21,1	0,9%	IDR.63	31,8	32,0	0,6%	IDR.93	IDR.183
Member 6	8,1	8,3	2,4%	IDR.24	18,4	18,6	1%	IDR.54	35,6	36,0	1,1%	IDR.105	IDR.183
Average			**2,3%**				**1%**				**0,9%**		

The data from the test analysis of the load cells reveals a trend of improving accuracy as the weight increases across all members. In the first test, the error percentage is highest, averaging 2.3%, with discrepancies in measurements leading to a corresponding balance earned ranging from IDR.18 to IDR.27. As the weight increases in the second and third tests, the error percentage steadily decreases to 1% and 0.9%, respectively. This trend suggests that the load cells show higher accuracy and performance with heavier loads, which may reflect better calibration or sensitivity at larger weights. Consequently, the balance earned by each member also increases with the weight, as the discrepancy between load cell and manual measurements widens in the earlier tests, resulting in higher compensation.

When examining the total balance earned across all tests, the figures indicate that the compensation is directly tied to the error percentage—members with larger discrepancies between the load cell and manual measurements earned higher amounts. For example, Member 3 earned the most, IDR.198, due to relatively higher error percentages in the earlier tests. This compensation structure rewards members based on the measured error, reinforcing the idea that the load cell's performance improves with larger weights and smaller measurement errors. Overall, the results highlight the load cell's progressive accuracy and its correlation with the amount of compensation awarded, offering insights into both the performance of the equipment and the design of the compensation system. Furthermore, table 1 is calculated using the following formula:

1. First Testing using one plastic of bottle waste
   a. $error = \left|\frac{9{,}4-9{,}5}{9{,}5}\right| \times 100\% = 2\%$
   b. $error = \left|\frac{6{,}5-6{,}7}{6{,}7}\right| \times 100\% = 2{,}9\%$
   c. $error = \left|\frac{9-9{,}2}{9{,}2}\right| \times 100\% = 2{,}1\%$
   d. $error = \left|\frac{7{,}6-7{,}8}{7{,}8}\right| \times 100\% = 2{,}5\%$
   e. $error = \left|\frac{9{,}5-9{,}7}{9{,}7}\right| \times 100\% = 2\%$
   f. $error = \left|\frac{8{,}1-8{,}3}{8{,}3}\right| \times 100\% = 2{,}4\%$

2. The second test using two plastic of bottle waste
   a. $error = \left|\frac{20{,}6-20{,}8}{20{,}8}\right| \times 100\% = 0{,}9\%$
   b. $error = \left|\frac{16{,}3-16{,}5}{16{,}5}\right| \times 100\% = 1{,}2\%$
   c. $error = \left|\frac{16{,}3-16{,}5}{16{,}5}\right| \times 100\% = 0{,}9\%$
   d. $error = \left|\frac{17{,}7-17{,}9}{17{,}9}\right| \times 100\% = 1{,}1\%$
   e. $error = \left|\frac{20{,}9-21{,}1}{21{,}1}\right| \times 100\% = 0{,}9\%$
   f. $error = \left|\frac{18{,}4-18{,}6}{18{,}6}\right| \times 100\% = 1\%$

3. The third test using three plastic of bottle waste
   a. $error = \left|\frac{34{,}4-34{,}8}{34{,}8}\right| \times 100\% = 1{,}1\%$
   b. $error = \left|\frac{32{,}7-32}{32}\right| \times 100\% = 0{,}6\%$
   c. $error = \left|\frac{36{,}3-36{,}8}{36{,}8}\right| \times 100\% = 1{,}3\%$
   d. $error = \left|\frac{34{,}2-34{,}6}{34{,}6}\right| \times 100\% = 1{,}1\%$
   e. $error = \left|\frac{31{,}8-32}{32}\right| \times 100\% = 0{,}6\%$
   f. $error = \left|\frac{35{,}6-36}{36}\right| \times 100\% = 1{,}1\%$

The first test was carried out using one plastic bottle waste, where plastic bottle waste got a value using a load cell of around 6.5 grams - 9.5 grams while the value using a manual scale was around 6.7 grams - 9.7 grams with an error value of 2.3%. Hence, this difference in weight was higher in value, namely manual scales. After that, the second test was carried out using two plastic bottle wastes, where plastic bottle waste got a weight value using a load cell, which was around 16.3 grams - 21.7 grams, and a value when using a manual scale, which was 16.5 grams - 21.1 with an average error value of 1%. Consequently, this weight difference was higher than that of manual scales. The third test used a load cell of around 31.8 grams – 36.3 grams and the value when using a manual scale is 32 grams – 36.8 grams with an error value of 0.9%. Based on the error values obtained from the previous calculations, all values are still in a state of tolerance. Therefore the difference in scale is still in a normal state.

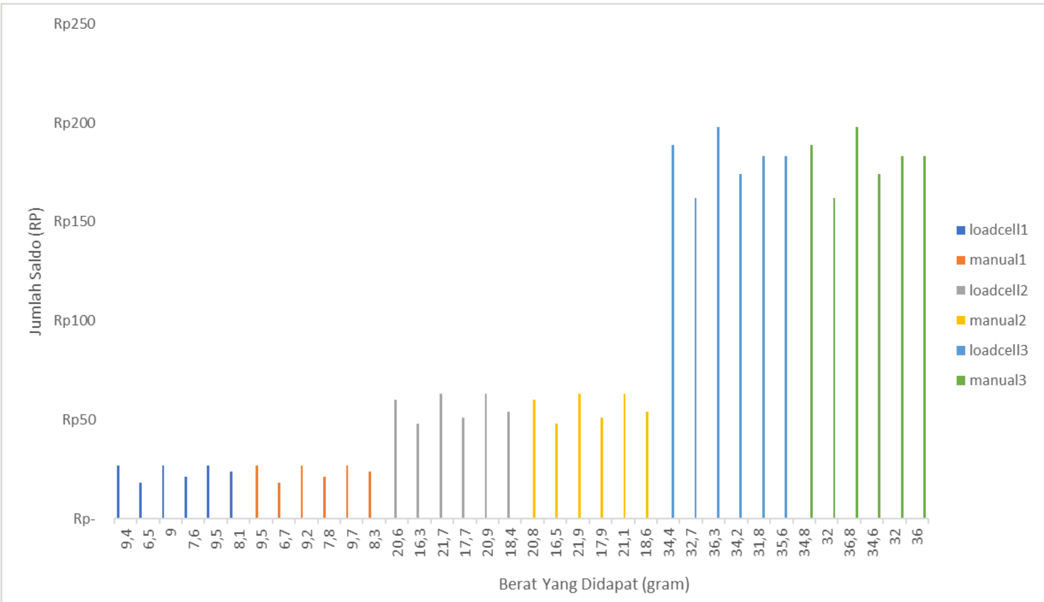

Figure 5 Results and Weight Obtained

From the picture above, it shows that each weight obtained on the loadcell scale will get a different weight. Because of the heavy influence obtained on plastic bottle waste fragments that do not enter the weighing, reducing the results of shredding plastic bottle waste that does not enter the scale. It has a great effect on the balance obtained by users. Each gram of plastic bottle waste shredding gets a balance of IDR.3/gram, as shown in the image above.

IV. Conclusion

The results showed that the average value on the scale was the first test, namely a load cell of 6.5 grams - 9.5 grams with a manual of 6.7 grams - 9.7 grams. The second test was 16.5 grams - 21.1 grams with a manual 16.5 grams - 21.1 grams, the second test was 31.8 grams - 36.3 grams with a manual 32 grams - 36.8 grams and from these results, the error value was still below 3%. This shows an increase in accuracy from test to test. The balance measurements also improved overall with the highest number of balances in the third test. From these results, it can be concluded that the measurement tools or methods used become more accurate along with the tests carried out and each balance obtained will adjust the weight of the balance results. Each weight of plastic bottle waste will be converted to a balance of IDR.3/gram

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