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Design and Development of Green Trash Compactor for Recyclable Waste Management

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ABSTRACT

A trash compactor is a mechanical device invented to reduce the volume of trash, making it suitable for use in various scenes such as domestic, public, and industries. Utilizing this kind of machine provides significant benefits in the waste accumulation system, as it allows for more efficient waste management by compacting the trash, enabling larger quantities to be collected at once. In this study, a Green Trash Compactor is designed and developed as an innovative semi-automated machine to efficiently reduce the size and volume of recyclable materials such as plastics, paper cups, and PET bottles. The project focuses on optimizing the sensor layout to minimize the impact during the compaction process, thereby reducing the requirement for heavy load cells or weight sensors. The working output is achieved by recording different input commands through buttons, where the system employs load cells to identify the detected force, and the microcontroller makes corresponding decisions. The results indicated that the Green Trash Compactor successfully operated with its mechanical and programmed codes, demonstrating impressive volume reduction during the compaction process. This substantial reduction in volume contributes to lowering transportation costs for the trash, making the compactor a highly efficient waste management solution.

Keywords: Recyclable waste, Trash compactor, Waste management

1. INTRODUCTION

The growing number of people attempting waste management and recycling activities is a positive sign for a healthy environment and sustainable outcomes [1][2]. This increasing awareness from the communities and industries plays a crucial role in reducing waste, conserving valuable resources, and mitigating the impact of human activities on the planet. As people become more conscious of their environmental footprint, the growth of the recycling industry has encouraged innovation in waste management technologies and processes, leading to more efficient and feasible practices.

Unlike general trash, green and recyclable waste must be classified and separated according to their respective types due to specific reprocessing methods employed for each. As a result, the growing stockpile of this categorized waste will fill up the transportation space before it can be sent to the respective facility. Indeed, to address this issue effectively, the industry has introduced a practical solution by developing a trash compactor. A trash compactor is a machine designed to compress and reduce the volume of solid waste, including household garbage and industrial waste, making it more efficient to handle, store, and transport.

The trash compactor objectively works by applying pressure to compress the waste, thereby minimizing the space occupied by the waste in a landfill or trash container. This process helps to maximize the capacity of waste containers, which allows for more efficient waste disposal, reduces the frequency of emptying the trash bins and lowers transportation costs [3]. According

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to [4], there are two types of trash compactors, which are manual bin type and automatic or smart bin type. The major difference between these bins is that the smart bin compactor uses sensors in the automatic system, enabling innovative functionality. However, it is worth noting that the automatic or smart system necessitates regular monitoring, whereas the manual system requires simple maintenance to ensure smooth operations.

Regarding compression, each compactor has a different compression rate. Hence, to optimize the system efficiency, the compactor needs different power outputs to be compatible with different types and amounts of waste. But in the currently available market, most compactors need more functions to adjust their power output to be compatible with various kinds of waste. If the compactor constantly operates with excessive power beyond the point where compression is most efficient, it could lead to unnecessary energy consumption, contributing to higher operating costs and potentially being environmentally wasteful.

Therefore, this study aims to design and develop a Green Trash Compactor that can efficiently compress and decrease the volume of solid waste, hence minimizing the space occupied by the waste in the trash container. By achieving effective compression, this innovative compactor will help improve waste management, leading to more efficient storage and transportation space uses. The project focuses on optimizing the sensor layout to minimize the impact during the compression process, thereby reducing the requirement for heavy load cells or weight sensors. The following section will describe the methodology for developing the Green Trash Compactor prototype.

2. METHODOLOGY

2.1 System Flowchart

Figure 1 illustrates the operation of the Green Trash Compactor system. Upon starting on the power, the system will enter a standby mode, awaiting the next step command activated by pressing a button. When the user presses a button, the system identifies the specific button that has been pressed, as there are initially two different modes, each corresponding to a unique output force for different waste categories. This variation is necessary due to different compaction rates and force requirements for different waste materials.

Once the button is selected, the system configures itself to the corresponding mode's setting, and the motor initiates rotation steadily to compact the waste. A load cell, connected to the base plate of the compactor, will measure the compaction force. If the force has not reached the required level, the motor continues rotating until the targeted force is achieved. Then, at this point, the motor stops, and reverses to retract the ram. After the ram is fully retracted, the load cell measures the total compacted trash inside the compactor and uploads this data to the cloud. The system then returns to standby mode, ready for the next trash compaction cycle, unless the user decides to turn off the power, which will end the entire system operation.

2.2 Hardware Design

2.2.1 Lead Screw

To perform the compression process, the Green Trash Compactor is equipped with a lead screw, also known as a power screw, to convert the rotational motion from gears into vertically linear motion. It comprises a threaded rod (screw) and a matching threaded nut. When the screw is rotated, the nut moves along the length of the screw, either in the axial direction (forward or backwards) or rotational motion.

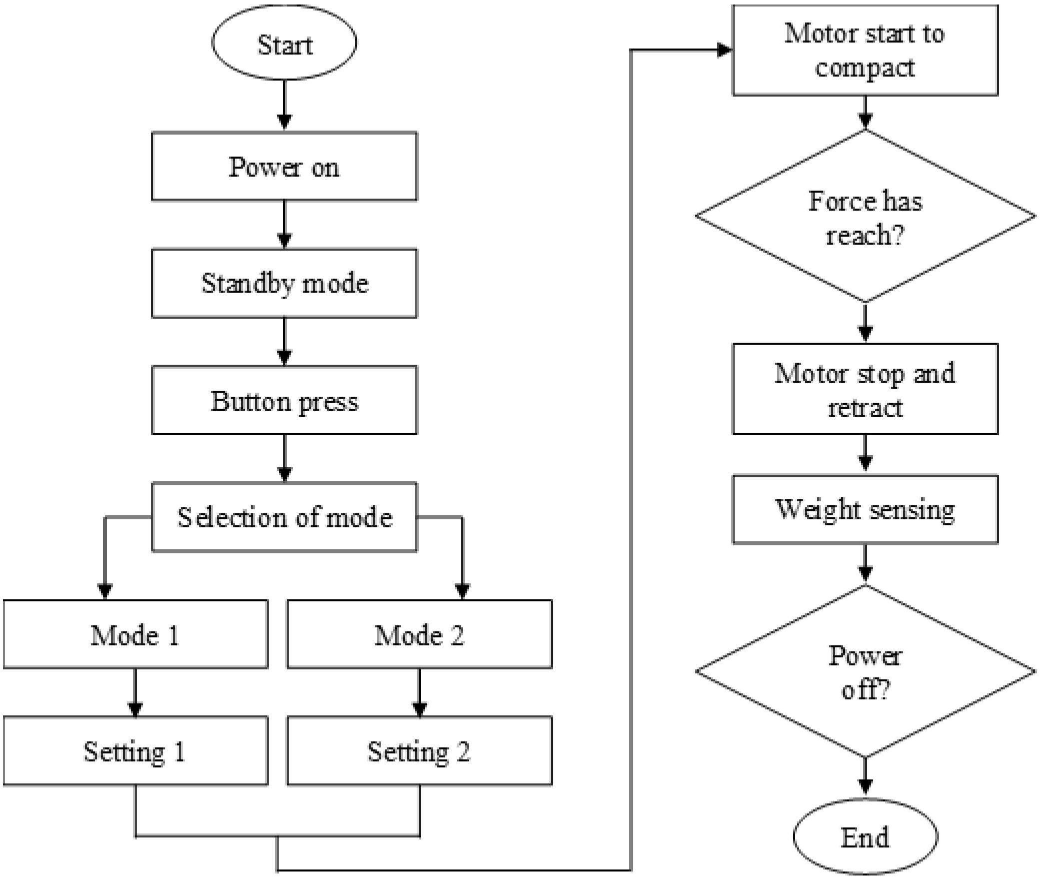


Figure 1. Flowchart of the Green Trash Compactor system

Compared to other linear motion mechanisms, such as belts or gears, lead screws are versatile components that play an essential role in numerous mechanical systems requiring precise and accurate linear motion and positioning [5]. Although they may be easily worn and torn, lead screws have relatively low costs due to their straightforward geometry, making them easy to manufacture.

In this study, the compaction mechanism was built using a 30 cm lead screw with a 1 mm pitch, as illustrated in Figure 2. Equation (1) calculates the number of rotations needed for a lead screw to drive to a specific distance. According to the equation, the total compression length of the lead screw is 300 rotations.

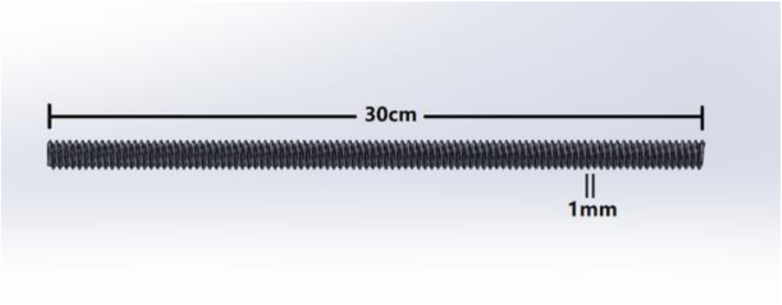


Figure 2. Dimensions of lead screw

$$\text{Number of rotation} = \frac{\text{Distance}}{\text{Lead}} \tag{1}$$

2.2.2 Gear

A gear is a mechanical component that consists of precisely designed toothed wheels to ensure proper engagement where rotational motion needs to be transferred, adjusted, or controlled. These teeth mesh with the teeth of other gears or toothed components to transmit motion and power between the rotating shafts. The size, shape, arrangement, and combination of the gears' teeth determine how the gears interact, influencing the machinery's speed, torque, and direction of rotational motion [6].

This study designed double helical gear due to their unique tooth structure of a V shape when the two helical sections are aligned and mounted side by side. The main advantage of this tooth structure is its ability to eliminate axial thrust forces. Combining two identical helical gears with opposite hands into one gear effectively counterbalanced the axial thrust generated by their meshing, cancelling its effect [7]. Moreover, the teeth positions on the right and left sides can be staggered strategically to minimize the excitation amplitude during gear meshing in the form of loaded motion transmission error and mesh stiffness fluctuations, further enhancing overall system performance [7].

Figure 3 illustrates the drawing of double helical gear. When designing a double helical gear, it is crucial to consider the varying curvature between the teeth of the larger and smaller gears. Typically, the teeth of the smaller gear must possess a higher curvature than those on the larger gear to ensure proper meshing and minimize stress on the gears.

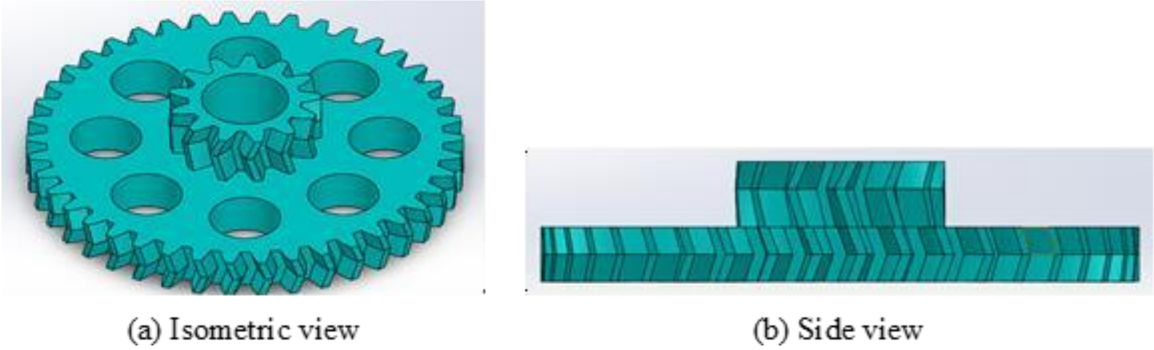

(a) Isometric view (b) Side view

Figure 3. Drawing of double helical gear

In the study, several equations are used to assist in the designing of the double helical gears, and these equations are as follows. Equation (2) is used to calculate the relationship between the teeth number of the gears and the diameter of the gear, while Equation (3) is used to calculate the speed of the gear rotation in rpm.

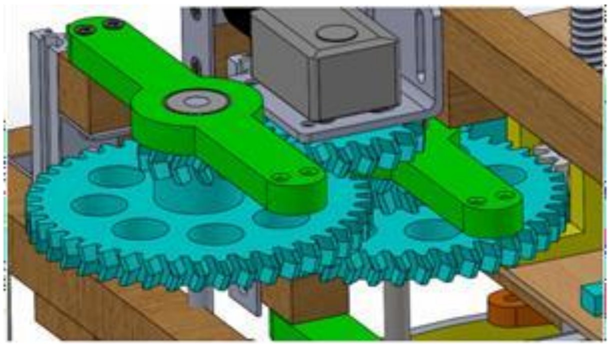
$$\frac{\text{Teeth of gear A}}{\text{Diameter of gear A}} = \frac{\text{Teeth of gear B}}{\text{Diameter of gear B}} \tag{2}$$

$$\frac{\text{RPM of drive gear}}{\text{RPM of follow gear}} = \frac{\text{Teeth of follower}}{\text{Teeth of driver}} \tag{3}$$

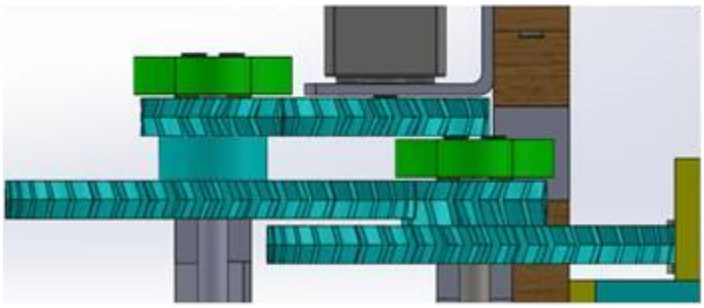
Initially, the fabrication of the hardware started by assessing the nut that is operated to mount into the lead screw. Therefore, a gear with a hexagonal hole perfectly fitting the nut is designed using SolidWorks CAD software. The angle used to draw the V-shape teeth of the double helical gear is 7°, whereas the number of teeth and the gear diameter are 12 and 2.86 cm, respectively. Next, to create a gearbox, a combination of gears must have a big and a small gear on each side to transfer the motion to the other gear. The calculation indicates that the bigger gear with a 10 cm diameter is designated to have a 2° angle of curvature and 42 teeth to connect with the smaller gear to form a gearbox.

This project uses a 5840-31ZY DC geared motor to convert and provide a rotation force. The motor speed is around 27 rpm (revolutions per minute). In order to simplify the gear ratio calculation, a gear used to mount below the motor will be constructed with 27 teeth, giving the angle and the diameter of the gears 3.11° and 6.43 cm, respectively.

Overall, the final gear will be around 746 rpm, where the gear rotation speed has been lifted from 27 to 746 rpm. Based on the calculation and values, the optimum ideal time for the lead screw to perform a full extension of 300 rotations is around 24 seconds, an acceptable duration. The final construction of the gearbox is shown in Figure 4.



(a) Isometric view of the gearbox



(b) Side view of the gearbox

Figure 4. Design of the gearbox

2.2.3 Load Cells

In the Green Trash Compactor, a load cell is used as the sensor that measures and provides the feedback of compression force to the control system, consequently preventing the compactor from being damaged or released too early [8]. The feedback data for the equilibrium-controlling system is presented by converting a mechanical force or load into an electrical signal proportional to the applied force.

Four HX711 load cells located at the baseplate are utilized to measure the total weight of the compacted waste and the force used while the system makes the compression. A load cell will convert the forces or loads applied into an electrical resistance which is then converted into an electrical signal through its sensing element, the strain gauge.

Figure 5 displays the layout of the load cells that are drawn in SolidWorks CAD software. The four load cells are mounted at each side of the circular plate, providing the force to be evenly distributed across the plate. This design is to support the load cells to withstand the high force generated during compactions.

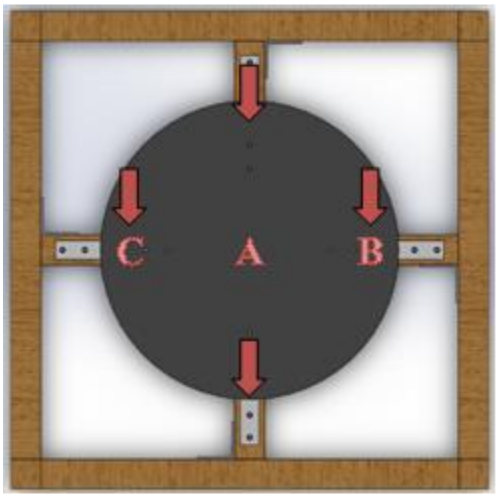


Figure 5. Layout of load cells installation

2.3 Hardware Construction

The Green Trash Compactor has various hardware components in addition to its design. These include a 5840-31ZY DC worm geared motor, an Arduino microcontroller, a motor driver with plate number BTS7960, a FURUKAWA super MF model FTZ12S battery and diverse 3D printed support branches. The total cost of the compactor amounts to MYR 419.87.

As predicted, a few problems have occurred throughout the construction process, necessitating modifications for the real hardware construction. Consequently, the final hardware design may differ slightly from the simulation design. Figure 6 illustrates the complete prototype of the Green Trash Compactor. The wood bar was selected as the main structure due to its low cost and simplicity for modification. The detailed specifications of the Green Trash Compactor are shown in Table 1.

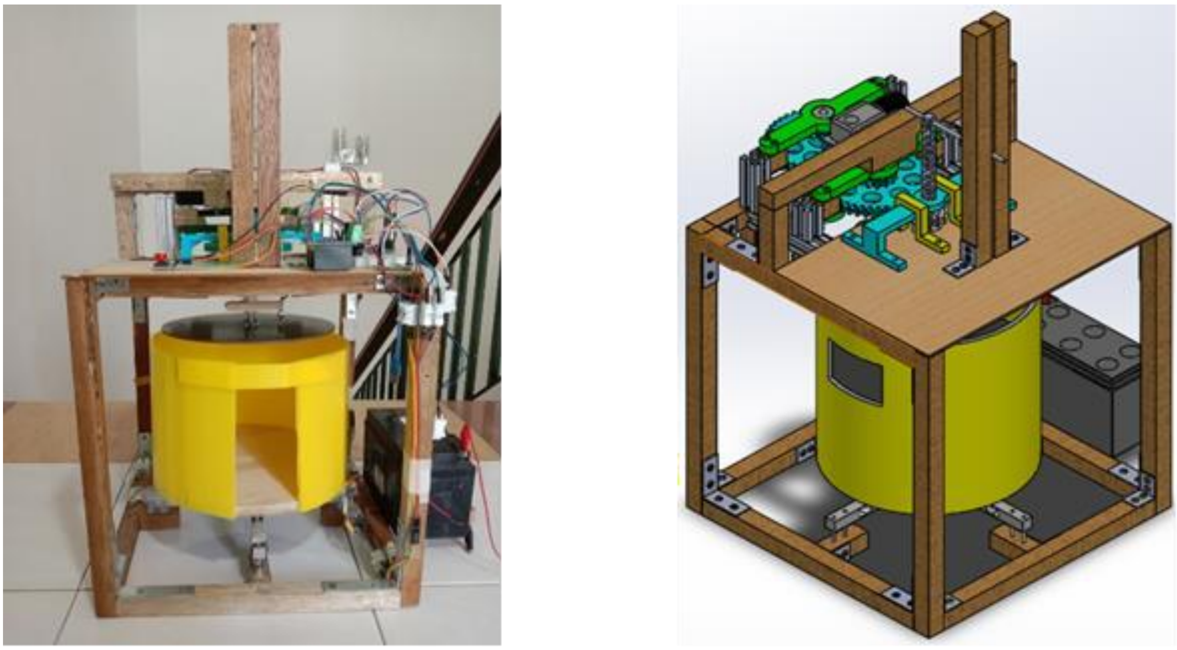

(a) Hardware prototype
(b) Simulation prototype

Figure 6. The Green Trash Compactor prototype

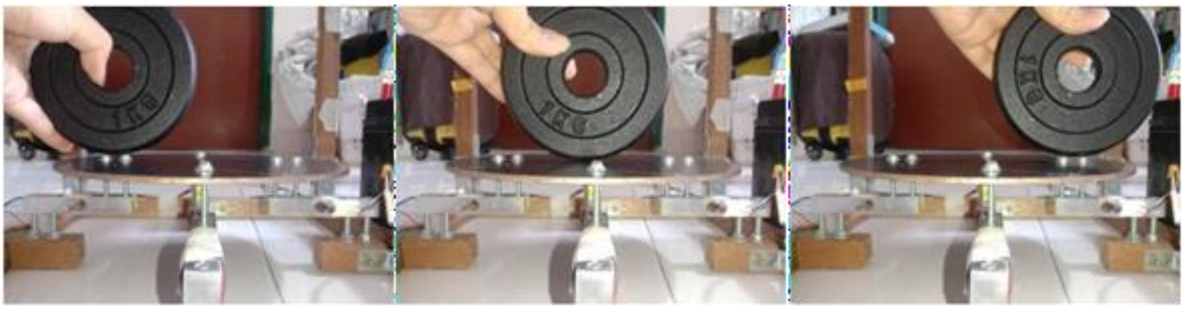
Table 1 Specifications of Green Trash Compactor

Specification	Value
Dimension	40 x 50 x 60 cm
Weight	8.5 kg
Operation voltage	12 v (motor) and 9 v (microcontroller)
Max operation hour (without rated current)	4 hours
Min operation hour (with stall current)	1 hour
Setting available	4 kg and 2 kg

3. RESUTLS AND DISCUSSIONS

3.1 System Validation

As previously discussed in the methodology part, when the position of the applied force is not at the centre of the plate, the detected weight will change. For validation, a 1 kg weight is positioned on the plate and moved from position A to position B, then position C (refer to Figure 5). The changes in weight data were received and plotted into a line graph to visualize the changes, as shown in Figure 8.



Position C Position A Position B

Figure 7. 1 kg weight is placed on the baseplate.

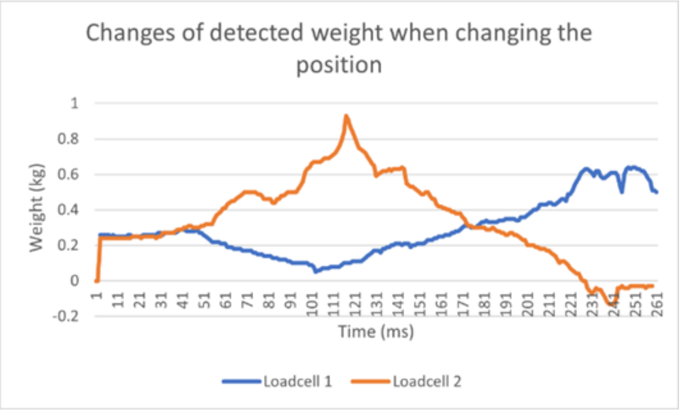


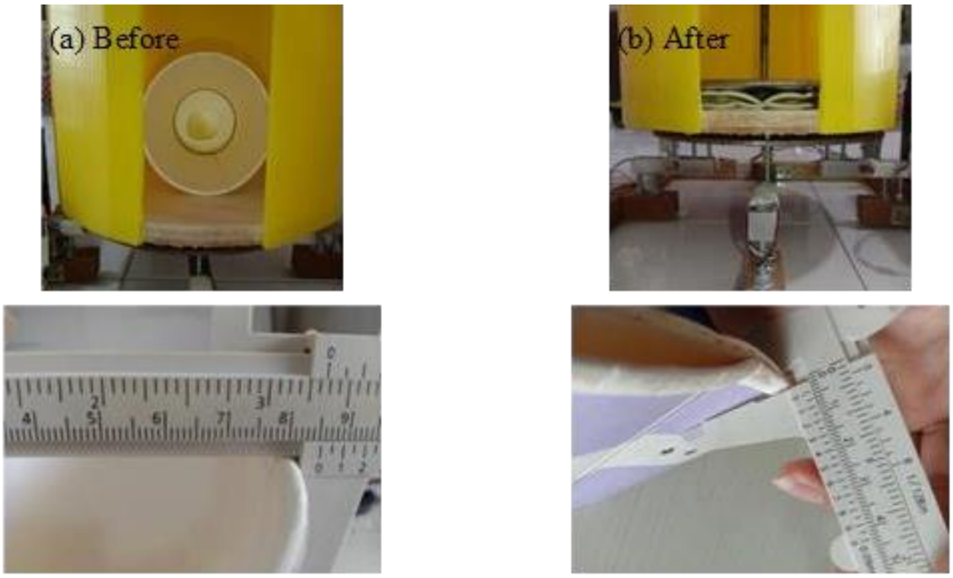
Figure 8. Changes of detected weight when 1 kg weight moves from A to B and C

The graph in Figure 8 displays the weight changes recorded by load cell 1 (position C) and load cell 2 (position B) during compaction of the 1 kg setting limit. The Y-axis represents the weight in kg, while the X-axis shows the changes in time in milliseconds (ms). Initially, both load cells started measuring the weight when the motor began to rotate and extend the lead screw. When the weight is located at the centre of the baseplate, both load cells recorded the force at similar values, indicating that the weight was proportionally distributed. However, at approximately 51 ms, the weight was shifted to position B, causing a gradual increase in the weight measurement at load cell 2 to nearly 1 kg. Meanwhile, the weight detected by load cell 1 (position C) is simultaneously decreasing since the weight is currently at position B, which is fully supported by load cell 2.

At about 121 ms, the weight is moved to position C to continue the test. According to the graph data, load cells 1 and 2 exhibited contrasting values, leading to a comparative outcome similar to the initial conditions. As a result, it is concluded that the layout can equally distribute the weight formed during the compaction. However, due to the circular baseplate layout, the detected weight will be unequal if the waste that needs to be compressed is off the center of the plate. Nevertheless, the system remains practical because its force distribution properties allow it to support higher forces. Moreover, the multiple load cells provide redundancy support, ensuring that the others can still operate effectively even if one load cell malfunctions.

3.2 Compaction Results

Figure 9 demonstrates the compaction process and the outcome of the compressed waste. Originally, the paper cup was approximated to have a cylindrical shape, and its pre- and post-compaction volumes can be calculated as presented in Table 2.



Diameter of paper cup before compacted   Thickness of paper cup after compacted

Figure 9. Compaction process and the outcome of the compressed waste

Table 2 Pre- and post-compaction volumes

Volume before compression process	Volume after compression process
$\text{Area} = \frac{\pi D^2}{4}$ $\text{Volume} = \text{Area} \times \text{Height} = 718.87\ \text{cm}^3$	$\text{Volume} = \text{Height} \times \text{Length} \times \text{Width} = 55.65\ \text{cm}^3$

Based on the tabulated data, the volume of the paper cup has been reduced by 92.26%, as shown in Equation (4).

$$\text{Volume change} = 100\% - \left[\left(\frac{55.65}{718.87}\right) \times 100\%\right] = 92.26\% \tag{4}$$

The compaction process resulted in a volume reduction of up to 92.26%, leading to 12 times more trash load in a single transportation. According to the objective of this study, the Green Trash Compactor has successfully maximized the capacity of waste containers, which allows for more efficient waste disposal, reduces the frequency of emptying the trash bins, and hence lowers transportation costs.

Nevertheless, a notable observation in extending the lead screw is that it required approximately 35 seconds to complete the extension. This duration contrasts with the earlier calculation detailed in Section 2.2.2, where the projected time for the lead screw to extend fully was around 24 seconds. This discrepancy between the estimated and observed time frames for the extension is primarily due to friction in the hardware system. During operation, the mechanical components, especially the gears, generate friction due to their high rotational speed and interaction. This friction, in turn, introduced resistance that hampered the smooth execution of the extension process. Consequently, the system's overall performance is impacted, leading to a reduction in its operational efficiency.

Several methods can be employed to mitigate the effects of friction and enhance the system's performance. One such approach is addressing lubrication between the gearbox [9]. Introducing a more significant quantity of grease or lubricant allows the spaces between the gearbox components to be effectively isolated, facilitating smoother movement and minimizing energy losses attributed to the frictional forces.

Furthermore, the design of the gears is a crucial aspect to consider. An optimized gear design, particularly the complex meshing between the individual gears, can significantly enhance the system's efficiency. By refining the geometry and alignment of the gear teeth, the interlocking action between gears can be made more seamless, decreasing the friction induced during the system's operation. This design enhancement would consequently contribute to smoother gear interactions, ultimately improving the overall performance of the hardware system.

4. CONCLUSION

Overall, the Green Trash Compactor prototype has been successfully designed and developed as an innovative and eco-friendly solution for waste management. By implementing sustainable design and efficient operation, the volume of waste has been significantly reduced. This advantage could promote recycling activities and greatly minimize waste accumulation, making them a crucial component of modern waste management strategies for a greener future.

There are several improvements in which the Green Trash Compactor can enhance its performance. At present, the prototype operates as a semi-automatic system. However, it can be upgraded to a fully automated system which automatically identifies the waste and self- calibrates the compaction force needed for the compression. Another area of improvement lies in the gearbox. The study suggests that adjustments must be made to the gear meshes to reduce greater friction between gears and improve the system's efficiency. Although the current wood used for building exhibits excellent properties, the wood may bend during gear rotation, hindering proper force and motion transfer in some instances. Switching to aluminium would address this issue and provide greater stability for the compactor's operation.

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