RESEARCH PROGRESS IN MECHANICAL AND MANUFACTURING ENGINEERING
e-ISSN: 2773-4765

RPMME

Vol. 7 No. 1 (2026) 253-262
https://publisher.uthm.edu.my/periodicals/index.php/rpmme

Design and Development of a Smart Cat Litter Box

Muhammad Irfan Burhanuddin[1], Mohd Fahrul Hassan[1*], Mohd Hamisa Abdul Hamid[2]

[1] *Faculty of Mechanical and Manufacturing Engineering*
Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, MALAYSIA

[2] *Faculty of Technology, Design and Management*
UCYP University, Kuantan, Pahang, 25050, MALAYSIA

*Corresponding Author: fahrul@uthm.edu.my
DOI: https://doi.org/10.30880/rpmme. 026.07.01.027

Article Info

Received: 10 December 2025
Accepted: 9 March 2026
Available online: 28 February 2026

Keywords

Cat litter box, Litter dispensing, Automated cleaning, SolidWorks

Abstract

The increasing demand for efficient cat litter management stems from challenges like odors, residue buildup, and unreliable self-cleaning systems. These issues often require manual intervention, creating inconvenience for pet owners. This study follows George E. Dieter's design methodology, covering conceptual, embodiment, and detailed design phases. Customer feedback gathered through surveys helped shape the product concept. SolidWorks was used for 3D modeling and structural analysis to refine the design. The smart cat litter box includes automated cleaning and litter dispensing systems to reduce odors and minimize manual maintenance. A proof-of-concept prototype confirmed the design's effectiveness. The final product measures 34 cm by 54.5 cm by 60 cm, and weighs 15.37 kg, providing a compact, efficient, and user-friendly solution for pet owners.

1. Introduction

The cat litter box plays a crucial role in promoting hygiene and natural waste elimination for cats. [1] Maintaining a clean litter box is essential to a cat's health, as improper cleaning can lead to undesirable behaviors like eliminating outside the box, which may strain the bond between cats and their owners. In some instances, this issue may result in a cat being surrendered to an animal shelter. [2] Cats are among the most popular pets in Malaysia, particularly in the Klang Valley, where a survey found that 67.6% of households with pets owned cats, making effective litter box management even more significant. [3] Although self-cleaning litter boxes have been introduced as a solution, many users experience frequent malfunctions. These systems often fail to detect usage accurately, resulting in incomplete waste disposal and persistent odors. This frequent failure of self-cleaning mechanisms causes frustration and compels users to intervene manually.

The goal of this project is to design and develop a smart cat litter box that meets customer needs and preferences. This will involve analyzing customer feedback from online platforms and conducting a survey in Sepang, Selangor, to identify common issues and desired features. Based on these insights, a 3D model of the litter box will be created in SolidWorks, and design simulations will be conducted to refine the concept. A proof-of-concept prototype will be developed with an automation process integrated using Arduino. The design emphasizes durability, ensuring the litter box performs reliably over time and enhances the living environment for both cats and their owners by having a self-cleaning system with an automatic litter dispenser.

Several patents have been instrumental in advancing the design and functionality of cat litter boxes, each introducing unique features to address common issues faced by pet owners. Karen Remick's 2020 patent presents a rectangular cat litter box designed for cleanliness and hygiene, incorporating antibacterial plastic materials. [4] A grated lid prevents litter scattering while offering comfort and safety, particularly deterring dogs from use. In contrast, Danny and Kellie Akers' 2019 patent introduces a dual-region system, distinguishing litter containment from recovery areas for improved cleanliness and convenience. [5] Their grated design efficiently collects excess litter, complemented by a detachable litter container and privacy-enhancing cover. Jose Federico Rodriguez's 2020 invention focuses on odor control and affordability, featuring an enclosed design with a vent for air circulation and a detachable tunnel for pet access. [6] This litter box also boasts portability with extendable legs and a lifting handle for ease of movement. In 2021, Anderson et al. patented an automated self-cleaning litter box with a motorized rake and a disposable receptacle for effortless waste removal. [7] Enhancements include a detachable ramp and porous mat to reduce litter tracking. Finally, Baxter et al.'s 2022 invention integrates advanced sensor technologies for automated processes, alongside a rotatable chamber for efficient waste disposal and enhanced space management. [8] These patents collectively redefine convenience and efficiency in litter box design.

Product benchmarking was conducted by analyzing three widely available cat litter box products in the online market. These products were selected based on their high sales volume and extensive customer reviews to ensure a thorough evaluation of popular and well-regarded designs. The benchmarking process focused on key aspects such as functionality, user feedback, and overall performance. The findings are presented in Table 1 below.

Table 1 *Available product in the market*

Specification	Product 1	Product 2	Product 3
Figure			
Brand Name	Vomlor	Petkit	Permarvel
Model Name	Self-cleaning cat litter box	Petkit Intelligent Automatic Cat Toilet Pura MAX	Petmarvel Magic Cube Smart Cat Toilet
Directions (Cat weight up to)	1.6 kg	1.5 kg - 1.8 kg	1.5 kg - 1.8kg
Material	Acrylonitrile Butadiene Styrene (ABS)	Polypropylene (PP), Acrylonitrile Butadiene Styrene (ABS), Thermoplastic Elastomer (TPE)	Acrylonitrile Butadiene Styrene (ABS)
Dimension (LxWxH)	20 x 50 x 50 (cm)	62 x 53.8 x 55.2 (cm)	52 x 54 x 68 (cm)
Weight (kg)	4	9.5	14.5
Price (RM)	849.55	1679	1690

2. Methodology

Figure 1 presents a structured overview of the product design process, based on the framework outlined in George E. Dieter's Engineering Design. [9] The process is divided into three main phases, which are conceptual design, embodiment design, and detailed design, with each phase consisting of distinct stages that contribute to the overall development of the product. In the conceptual design phase, the problem is defined, and potential solutions are generated. The embodiment design phase refines these concepts and focuses on the physical structure of the product. The final phase, detailed design, ensures that the product's components and functions are fully specified and integrated. The flowchart concludes with the results and discussion section, which highlights the outcomes of the design process, followed by the conclusion. This final section summarizes key findings and provides recommendations for improvements. Each phase is integral to creating a well-rounded and functional product design.

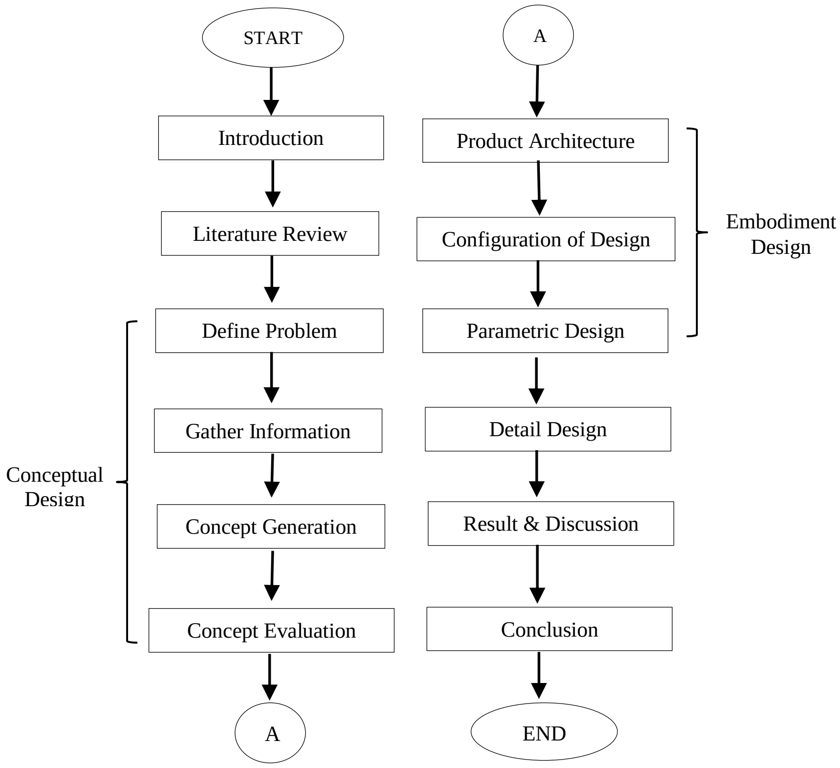

Fig. 1 *Flowchart of the design process*

3. Results

A survey was conducted to gather insights into customer preferences for a new cat litter box innovation. The data was collected using Google Forms and targeted the Sepang, Selangor community. The survey consisted of three key sections which included demographic and anthropometric details, litter box management issues, and desired improvements. The survey results were analysed to create an objective tree illustrated in Figure 2. This tree organizes and prioritizes the design objectives into three main categories which are user convenience, robustness, and cost. By assigning relative weights to these objectives, the most critical elements were identified to ensure design decisions focus on addressing the users' priorities effectively.

The concept of a House of Quality (HOQ) is used to connect consumer needs with engineering solutions in product design. This approach translates customer requirements into specific technical specifications, helping to align the product design with user expectations. The product design specifications, derived from the survey results and prioritization efforts, are shown in Table 2. These specifications provide clear guidelines for the development of a functional, durable, and user-friendly cat litter box that meets customer demands effectively.

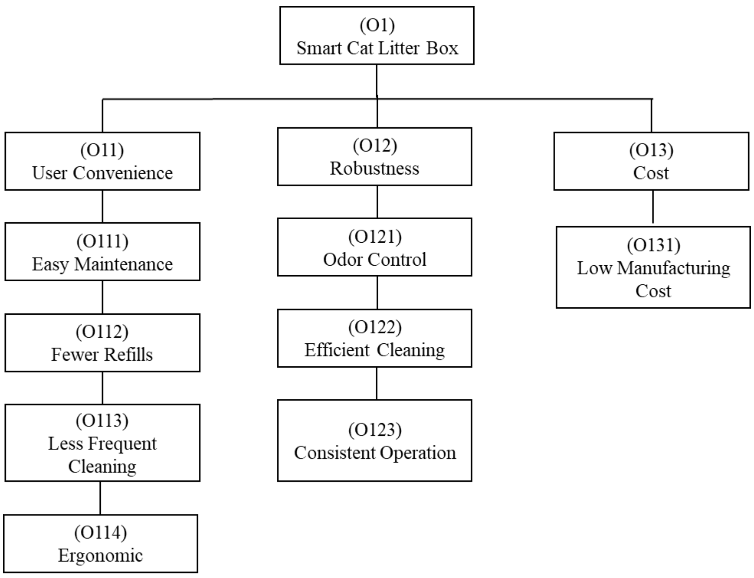

Fig. 2 *Objective tree of the smart cat litter box*

Table 2 *Product Design Specification*

Introduction	
Title	Smart cat litter box
Design Problem	To minimize litter box maintenance work by human
Intended Purpose	To reduce odor problem
Special Features	Litter self-dispenser
Customer Requirement	
Affordable Cost	The product should cost RM 300 or less
Ergonomic Design	Easy to use and handle, targeting comfort and reducing strain
Sustainable Operation	Durable materials designed to last a minimum of 5 years
Automatic Litter Refill	The product should have a capacity of at least 5 liters for litter and include an automatic refill feature
Efficient Waste Cleaning	The waste cleaning system should work without causing any spills or mess
Odor Control	It should have a good ventilation system to keep the area odour-free
Reliable Performance	The product should work well with fewer than 2 breakdowns per year
Appearance	The product should feature a modern design that seamlessly complements any home decor

3.1 Conceptual Design

To generate a concept, begin by employing a concept map, an effective tool for organizing ideas and systematically developing solutions. This process progresses through physical decomposition, where individual components are analyzed for their contributions to the overall system, and functional decomposition, which illustrates the integration of these components into a cohesive operation. The function structure, as depicted in Figure 3, is derived from the functional decomposition.

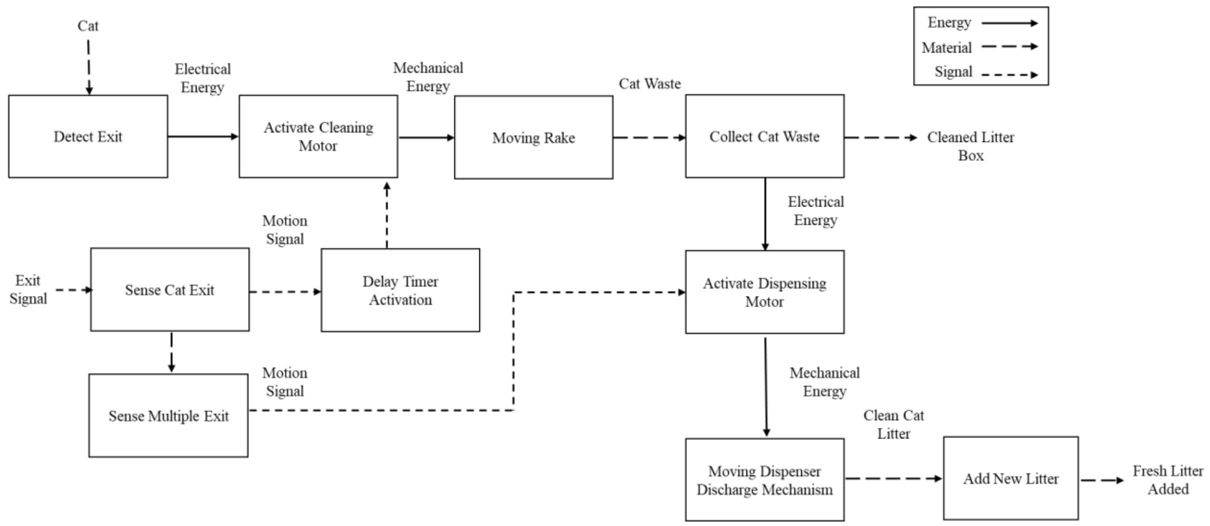

Fig. 3 *Function structure*

The morphological chart is a critical method for exploring alternative solutions to meet the desired product functions. This approach organizes various concepts for each function into a table, offering a clear overview of possible combinations. Subsequently, three distinct combinations are developed during the concept generation stage. These combinations are then evaluated using a decision matrix. Weighting factors, derived from the objective tree, are applied in this process to prioritize customer requirements. By scoring each alternative and applying the weightage, the concept with the highest overall rating is selected. The selected concept is presented in Table 3.

Research Progress in Mechanical and Manufacturing Engineering Vol. 7 No. 1 (2026) p. 253-262

Table 3 *Product specification of the smart cat litter box*

No	Function	Selection Concept
1	Entry Path	Open rectangle
2	Cat Detection	Ultrasonic sensor
3	Cleaning	Rake mechanism
4	Motor Type	Servo motor
5	Waste Disposal	Direct drop into the waste bin
6	Litter Storage	Detachable container
7	Litter Dispensing	Gravity-fed
8	Ventilation	Fan ventilation
9	System Power	Direct power
10	Container Maintenance	Detachable

3.2 Embodiment Design

The initial phase of the embodiment design process involves the creation of the product architecture, which serves as the foundation for the detailed design and development of the system. This stage begins by drawing a schematic diagram that clearly represents how the product functions and how it will achieve its intended objectives. The schematic diagram acts as a visual guide to demonstrate the interaction of various components within the system. Following this, elements are grouped into logical clusters based on shared characteristics, facilitating the organization and optimization of the system's components. Each cluster functions as an independent unit, and its placement is determined to ensure the efficient operation of the overall design, as illustrated in Figure 4. This approach facilitates the creation of a preliminary geometric layout, enhancing the understanding of component interactions within a unified system.

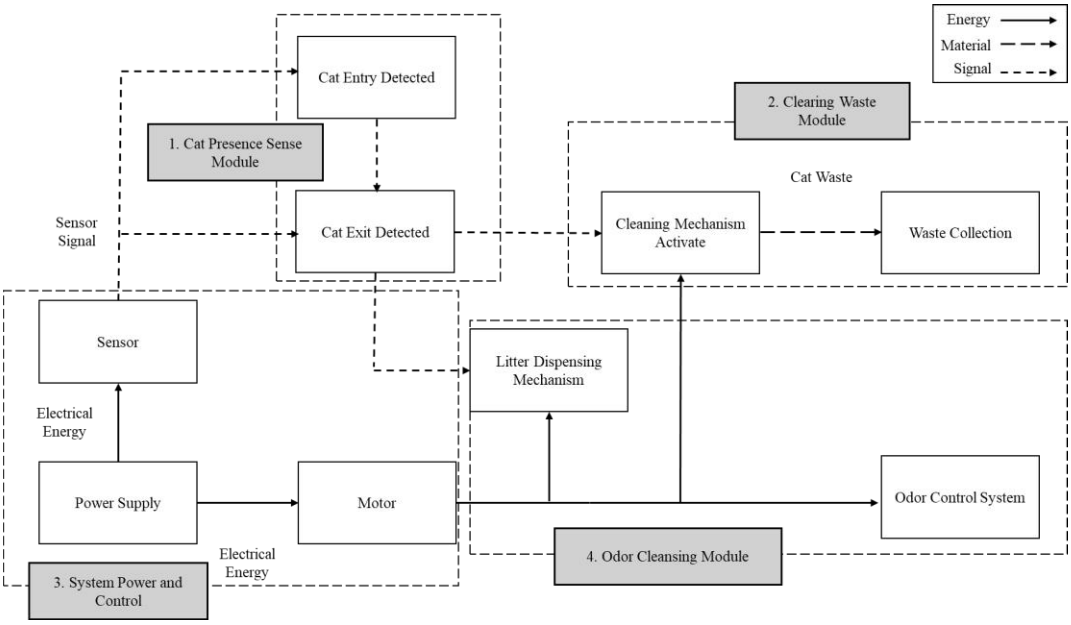

Fig. 4 *Schematic diagram with clustered elements*

3.3 Detail Design

The product is designed in SolidWorks, ensuring accurate measurements and simulations for optimal functionality. Figure 5 illustrates the exterior design, which features the base, upper base, litter container, and waste bin. The wide base provides stability and supports the upper base, which includes a large front window to allow easy cat entry and exit. It also offers sufficient internal space for the cat's movement. Positioned above the upper base, the litter container holds a substantial amount of litter, reducing the need for frequent refills and minimizing maintenance. The waste bin, located at the front, has a large capacity to minimize the frequency of emptying collected cat feces. Equipped with a grip for easy handling, it can also serve as a step for the cat. Inside, the system includes a rotating rake to direct waste into the bin, and a rotating litter flap that dispenses litter only when necessary, ensuring a clean environment inside.

The rake mechanism starts from its initial position at the back of the litter box, providing sufficient space for the cat to enter. During operation, the rake rotates forward, guiding the cat feces toward the designated waste bin positioned below the cleaning mechanism. The rotation progresses until the rake achieves a specified angle of 74.61 degrees, ensuring the waste is properly dropped into the bin. After completing this process, the rake returns to its initial position, prepared for subsequent operation cycles. Figure 6 illustrates the rake mechanism during its rotational operation for cleaning process.

Next, the litter flap mechanism is to facilitate the passage of litter through a motorized flap. Gravitational force moves the litter downward to the litter base. Upon completion of the cleaning process, the flap rotates 90 degrees, allowing the litter to flow into the litter base. The motorized flap remains open briefly before returning to its initial position, thereby closing the flow. Figure 7 shows the movement of the litter flap during the litter dispensing operation.

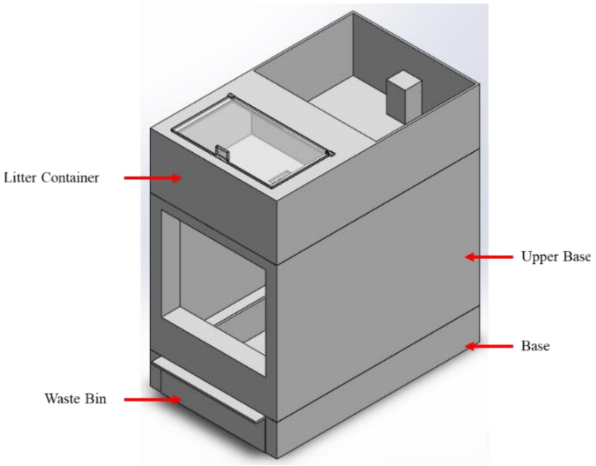

Fig. 5 Full assembly of the Smart Cat Liter Box

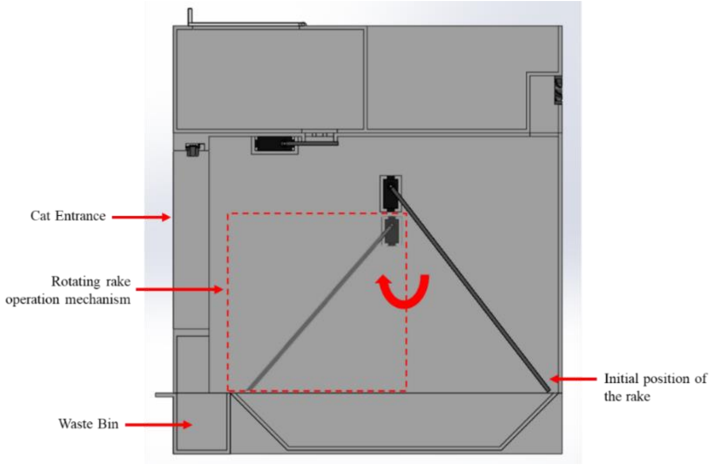

Fig. 6 The rake mechanism of rotation

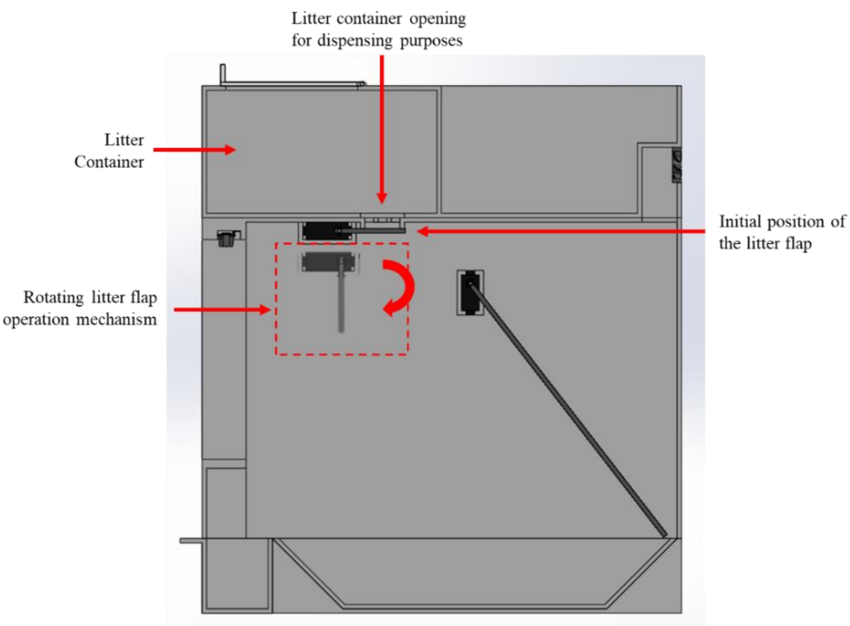

Fig. 7 The litter flap mechanism of rotation

The motor selected for the rake system is determined through a detailed torque calculation based on the variables outlined in Table 4, ensuring that it provides sufficient and reliable torque for the efficient operation of the cleaning mechanism. After determining the required torque, the motor's power requirements are then calculated, which enables the estimation of the total power consumption for the product design. This design employs two distinct motors to perform separate functions for the rake system and the litter dispenser system.

Table 4 *Data for torque and power calculation*

No	Detail	Specification	No	Detail	Specification
1	Mass of cat feces (g)	200	6	Mass of the litter flap (kg)	0.02
2	Coefficient of friction	0.5	7	Rake length (mm)	360
3	Rake rotation time (s)	10	8	Litter flap length (mm)	80
4	Litter flap rotation time (s)	5	9	Angle of rotation for the rake (˚)	74.61
5	Mass of the rake (kg)	0.2			

Calculate the torque of motor for the rake mechanism, τ_1 by using formula:

$$\text{Torque}, \tau = F \times r \tag{1}$$

Where, F = Frictional force; r = The distance from the pivot point to the point where the force acts. The frictional force is determined by the following formula:

$$\text{Frictional force}, F = \mu \times N \tag{2}$$

Where, μ = Coefficient of friction; N = Normal force. The normal force is to be the sum of mass of the cat feces with the mass of the rake.

$$F = 0.5 \times [(0.2 + 0.2)\ 9.81]$$
$$F = 1.96\ N$$

The required torque for the rake mechanism motor is determined by calculate the total frictional force with the rake length as shown below:

$$\text{Torque for the rake mechanism}, \tau_1 = 1.96 \times 0.36$$
$$\tau_1 = 0.7056\ Nm\ @\ 7.2\ kg/cm$$

Next, calculate the motor power for the rake mechanism, P by using formula:

$$\text{Power}, P = \tau \times w \tag{3}$$

Where, τ = Torque; w = The angular velocity. The power of motor for the rake mechanism is calculated as shown below:

$$\theta = \frac{74.61^\circ}{180} \times \pi$$
$$= 1.302\ rad$$
$$P_1 = 0.7056 \times \frac{1.302}{10}$$
$$= 0.1\ W$$

Then, calculate the torque of motor for the litter flap mechanism by determining the force required. The force of the system is taken out directly by the weight of the litter flap component itself. Then, the required torque for the litter flap mechanism motor is determined by multiplying it with the litter flap length and the result as shown below:

$$\text{Torque for litter flap mechanism}, \tau_2 = [(0.02 \times 9.81)] \times 0.08$$
$$\tau_2 = 0.016\ Nm\ @\ 0.16\ kg/cm$$

Next, the motor power for litter flap mechanism can be calculated through define the angular rotation of the system itself. The design of the litter flap mechanism is to rotate the litter flap component 90 degrees to allow the litter to pass by through it. The operation is estimated to be in 5 seconds before it returns to its initial position. The litter flap motor power is calculated as shown below:

$$\theta = \frac{90^\circ}{180} \times \pi$$
$$= 1.5708\ rad$$
$$P_2 = 0.016 \times \frac{1.5708}{5}$$
$$= 0.005\ W$$

Hence, Table 5 shows the motor that will be chosen for each mechanism. The selection of the motor is selected by choosing the same of bigger torque output from the required gets from the calculated analysis.

Table 5 *Motor specifications*

Motor Type	Specification			
	Voltage, V	Stall Torque, kg/cm	Speed, Sec/60 degree	Weight, g
FS5109M	6	10.2	0.16	56
FS9225M	6	5.2	0.12	29

Mass flow rate analysis is essential for determining the amount of mass transferred over a specific period, ensuring consistent dispensing of cat litter into the litter base. The cross-sectional area, obtained from the detailed design drawings of the litter container, represents the opening through which the litter passes. By accounting for the density of the cat litter (0.8 to 1.11 g/cc), the velocity can be accurately calculated. The calculation for the mass flow rate can solve through the formula shown below:

$$\text{Mass flow rate, } \dot{m} = \rho \times A \times V \tag{4}$$

Where, ρ = Density; A = The cross-sectional area; V = Velocity. The velocity value can be obtained by calculating the height from which the litter is dropped, measured from the opening path to the litter base. This height is determined from the detailed design, which combines the upper base height and the litter base height. As the velocity is governed by gravitational force, it is calculated using the following formula:

$$\text{Velocity, } V = \sqrt{2 \times g \times h} \tag{5}$$

Where, g = The gravitational force; h = The height of the litter to be dropped. The height from which the litter is dispensed has been measured as 435 mm, while the cross-sectional area of the opening for the litter dispenser is determined to be 1.2×10^{-4} m^2. The mass flow rate can be calculated based on these values as outlined below:

$$\text{Velocity, } V = \sqrt{2 \times 9.81 \times 0.44}$$
$$= 2.92\ m/s$$

The amount of litter that will be dispensed by the litter flap mechanism is shown below:

$$\text{Mass flow rate, } \dot{m} = 800 \times 1.2e^{-4} \times 2.92$$
$$= 0.28\ kg/s$$

The weight value for the litter container testing structure is calculated based on the estimated density of cat litter, multiplied by the volume of the container. Results from the von Mises stress analysis reveal a maximum stress of 0.7120 MPa as shown in Figure 8. Additionally, displacement analysis indicates a maximum displacement of 0.57 mm shown in Figure 9, and the calculated strain is $1.809e^{-4}$. The analysis results confirm that the litter container design is structurally sound. The stress, displacement, and strain values are all within the safe limits of the ABS material properties. This indicates that the container can effectively withstand the weight of the litter while maintaining its structural integrity and functionality.

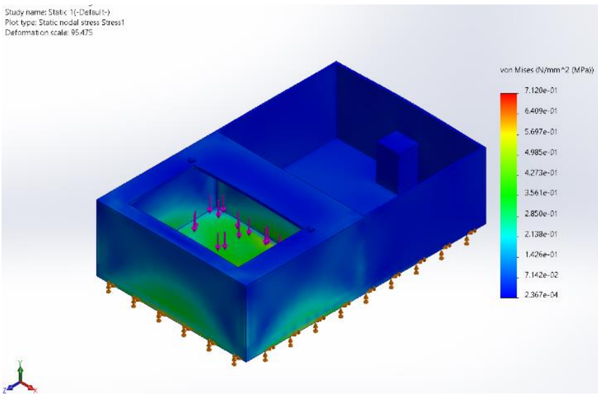

Fig. 8 Von mises stress analysis

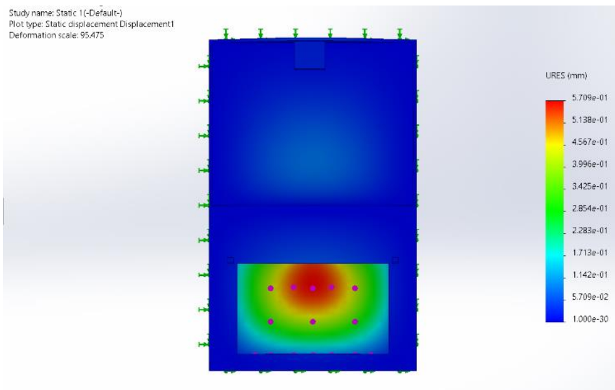

Fig. 9 Displacement analysis

The completion of the component design leads to the creation of detailed product specifications that align with operational requirements and earlier calculations. This section provides all the necessary data about the product's features, offering clear and accurate information for customers and other stakeholders. Table 6 shows the product specification of the smart cat litter box.

Table 6 *Product specification of the smart cat litter box*

Detail	Product Specifications
Weight (kg)	15.37
Voltage (V)	6
Power (W)	0.11
Price	RM280.99
Dimension (W × L × H)	$34\ cm\ \times 54.5\ cm \times 60\ cm$

3.4 Product Prototype and Testing

The proof-of-concept prototype was developed to test the functionality of the smart cat litter box design, as shown in Figure 10. Inspired by George E. Dieter's "quick prototype" approach, this initial model serves as an early-stage representation of the concept. It was built using a rectangular storage box with internal partitions made of cardboard. A circular plastic container was used to hold the litter, while a white rectangular plastic container acted as the base for the litter area. Lightweight materials, such as cardboard, were chosen for parts like the rake to simplify testing.

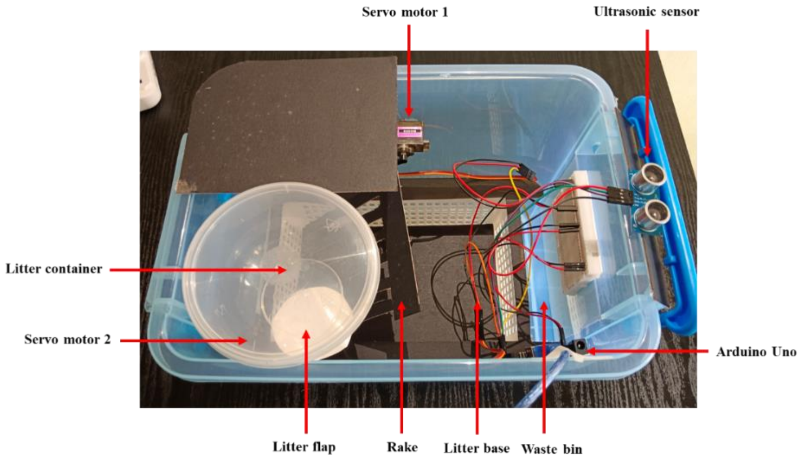

Fig. 10 Full assembled prototype

Testing focused on the two key mechanisms which is the rake and the litter dispenser. The rake system, powered by an MG90S servo motor, was connected to a circuit designed in Tinkercad and programmed using Arduino IDE. The ultrasonic sensor detected when a hand (simulating a cat) entered and exited the box, as shown in Figure 11. To ensure safety, the rake activated only after the sensor detected two distinct signals, confirming the simulated cat had left. The rake successfully swept the waste forward and returned to its starting position, illustrated in Figure 12.

The litter dispenser was programmed to operate after every two complete rake cycles. After the second detection in the second cycle, the motor rotated the dispenser litter flap to release fresh litter into the box. This sequence was designed to shorten testing time for demonstration purposes. Ideally, the frequency of litter dispensing would be adjusted through coding, as it is less frequent than waste-clearing operations. This initial prototype successfully demonstrated the functionality of both mechanisms.

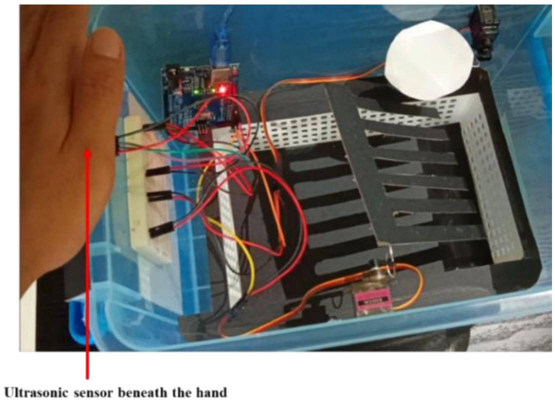

Fig. 11 Simulated hand triggering the sensor

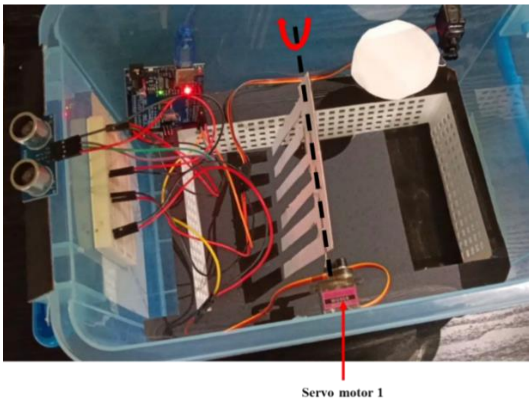

Fig. 12 Rake mechanism in operation

4. Conclusion

In conclusion, the objectives of this project were successfully accomplished by following a systematic approach based on the product design process by George E. Dieter. This structured framework provided a clear pathway from conceptualization to final product development, ensuring each phase was thoroughly analyzed and aligned with customer requirements and survey insights. The primary aim of the design was to minimize the frequency of cleaning the cat litter box by integrating an automated cleaning mechanism that sweeps away cat feces and stores it securely. This ensures the box remains clean, eliminating issues with unpleasant odors. As a result, pet owners can enjoy a comfortable living space that is free from unpleasant smells.

Key features of the design include an automated litter dispenser that replenishes the litter after the cleaning cycle, significantly reducing manual involvement. The waste bin component is designed to accommodate several days' worth of waste, requiring only periodic emptying. Comprehensive testing was conducted to guarantee reliability, including von Mises stress, displacement, and strain analyses, ensuring durability and preventing design failures. The final product, weighing 15.37 kg and measuring 34 cm x 54.5 cm x 60 cm, seamlessly integrates functionality, durability, and convenience. It effectively meets the needs of cat owners, enhancing their overall experience and simplifying the management of pet care.

Acknowledgement

I would like to express my sincere gratitude to Prof. Madya Dr. Mohd Fahrul bin Hassan, my project supervisor, for his invaluable guidance, constructive feedback, and continuous support throughout the completion of my final thesis project. His expertise and encouragement have been instrumental in achieving the goals of this research. I would also like to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, for providing the resources and support needed for the successful completion of this project. Lastly, I am deeply thankful to my family and friends for their unwavering support and encouragement, which was a source of strength during this journey.

References

[1] Heath, S. (2019). Common feline problem behaviours: Unacceptable indoor elimination. Journal of Feline Medicine and Surgery, 21(3), 199–208. https://doi.org/10.1177/1098612X19831202
[2] Frayne, J., Edwards, M., Templeman, J. R., Croney, C. C., Macdonald-Murray, S., Flickinger, E., Verbrugghe, A., & Shoveller, A. K. (2022). The Behavioural Impact on Cats during a Transition from a Clay-Based Litter to a Plant-Based Litter. Animals, 12(8). https://doi.org/10.3390/ani12080946
[3] Munir, S. M. I., Mokhtar, M. I., & Arham, A. F. (2023). Public perspectives on strays and companion animal management in Malaysia. BMC Public Health, 23(1). https://doi.org/10.1186/s12889-023-16276-5
[4] Remick, K. (2020). Cat litter box (Patent 10,624,309 B2)
[5] Danny W. Akers, I., & Kelle C. Akers. (2019). Catch drawer litter box (Patent 2019/0014738 A1)
[6] Rodriguez, J. F. (2022). Encapsulated litter box (Patent 2022/0087210 A1)
[7] Anderson, D., Wright, R., Brent, D., Favia, A., & D. Himes, W. (2021). Automated self-cleaning litter box having disposible recepticle and methods (Patent 2021/0251182 A1)
[8] Baxter, Smith, & Weihman. (2022). Automated litter device (Patent 3 945 792 B1)
[9] Dieter, G. E., & Schmidt, L. C. (2013). *Engineering design*. McGraw-Hill