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Improvement on the Design of a Palm Fruit Lifting Device for Trucks

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Abstract

The manual loading of fresh fruit bunches (FFBs) in the Malaysian oil palm sector is a labour-intensive process associated with a high prevalence of musculoskeletal disorders among workers. While mechanised lifting solutions have been proposed, previous prototypes have proven impractical for remote plantations due to excessive weight (over 370 kg), suboptimal lifting speeds (0.78 m/s), and a reliance on stable electrical grids. This study presents the design and simulation of an improved, field-adaptable FFB lifting device engineered to overcome these limitations. Utilising SolidWorks for 3D modelling and kinematic simulation, the redesign focused on three key optimisations: achieving a lightweight footprint under 250 kg, integrating a flexible and foldable structure for transportability, and implementing an independent engine-driven power transmission system. Results demonstrate that the redesigned mechanism, equipped with an engine and gearbox, successfully achieves a lifting speed of 0.96 m/s, closely meeting the 1.0 m/s industry target. By significantly enhancing portability and eliminating grid dependency, this improved device provides a highly viable, ergonomic, and cost-effective solution for small- to medium-sized plantation settings.

1. Introduction

The oil palm is a critical commercial crop that originated in Africa and is extensively grown in Southeast Asia. With 27% of global production in 2021-2022, Malaysia is currently the second-largest producer in the world [1]. While the industry is important to the country's economy, the manual harvesting and loading of Fresh Fruit Bunches (FFBs) remain highly labour-intensive. The workers frequently handle bunches weighing between 5 kg and 50 kg, leading to severe ergonomic risks and musculoskeletal disorders (MSDs), with up to 94.3% of workers reporting back pain[2][3].

To address these risks and simplify the loading process, a previous study by Wan Sayyidil Athir developed an automated lifting device using a motor-driven conveyor system. However, this existing design has several limitations, including reliance on steady electricity, a total weight of 370.56 kg, and a non-foldable structure that makes transportation more difficult in isolated plantation environments. Additionally, the industry requirement of 1.0 m/s was not met by the previous lifting speed of 7.8 m/s [4].

This project aims to improve the lifting device design by emphasizing three key aspects: reducing weight to less than 250 kg, switching to a self-sufficient engine-driven system, and installing a flexible, foldable structure. To maximize performance and portability, the study uses SolidWorks software to create 3D models and execute motion simulations. By resolving these issues, the study offers a more effective and field-adaptable way to improve worker productivity and safety in the palm oil industry.

Wan Sayyidil Athir Bin Wan Mohd Zulkifli developed the earlier palm fruit lifting apparatus, a conveyor system that used a chain-and-sprocket mechanism to automatically load bunches of palm fruit onto trucks. By using an electric motor and generator to transfer rotational force through a shaft and move fruits upward along an inclined route, the device sought to lower the health and safety concerns associated with manual work. Among its benefits were a lifting height of more than 2 meters and a load capacity of about 120 kg, exceeding the client's initial requirement of 100 kg. Additionally, the design included robust elements intended to withstand harsh plantation conditions for a 10-year lifespan, such as a conveyor frame, a secure path to minimize fruit loss, and pillow block bearings to maintain smooth operation. Fig. 1 shows an isometric view of the palm fruit lifting device he designed.

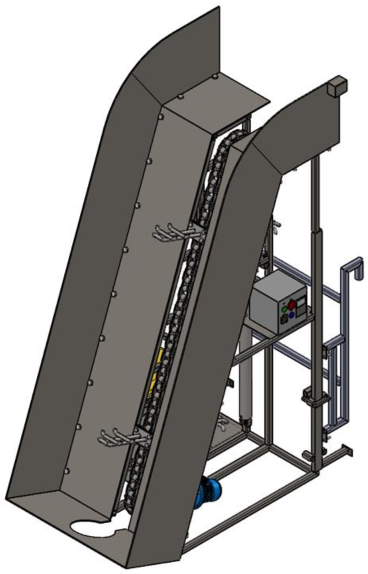


Fig.1 *Palm Fruit Lifting Device designed by Wan Sayyidil Athir [4]*

Despite these useful features, the project had several serious drawbacks that made it difficult to use in real-world settings. Transportation and storage were challenging because the structure's total weight of 370.56 kg was well above the client's desired limit of 100 kg or less. Performance-wise, the lifting speed was just 0.78 m/s, falling short of the industry standard of 1 m/s. Furthermore, the total production cost was RM 23,256.61, which is more than four times the anticipated selling price of RM 5,500. The device's huge, non-foldable proportions limited manoeuvrability in small plantation fields, and its dependency on a motor-driven system rendered it impractical for remote locations without electricity.

2. Methodology

The methodology for the palm fruit lifting device follows a systematic engineering framework adapted from George E. Dieter's design process, structured into conceptual, embodiment, and detail design phases [5]. In the conceptual phase, the design problem is defined by establishing a clear issue statement and a Product Design Specification (PDS) matrix to translate user needs into measurable engineering characteristics. Information is then gathered from internet sources, patent databases, and technical journals to identify relevant materials and technologies. The study modified the project methodology by bypassing the concept generation and evaluation stages, as the fundamental requirements and client data were reused from previous work.

The embodiment design phase organises the selected concept into a modular arrangement of physical subsystems, defining the preliminary material selection and manufacturing processes. This phase includes parametric design, where critical variables are integrated into CAD models to improve performance and manufacturing feasibility. The detail design phase concludes the process with the delivery of shop-ready documentation, including comprehensive engineering drawings, dimensional tolerances, and a bill of materials.

Finally, SolidWorks animations and simulations are utilised to illustrate the functionality and operating principles of the improved conveyor system, verifying that it satisfies all technical requirements. By following this systematic methodology, the project ensures that the final design is ergonomic, practical, and aligned with the client's needs. Fig. 2 shows the modified flowchart of the design process introduced by George E. Dieter.

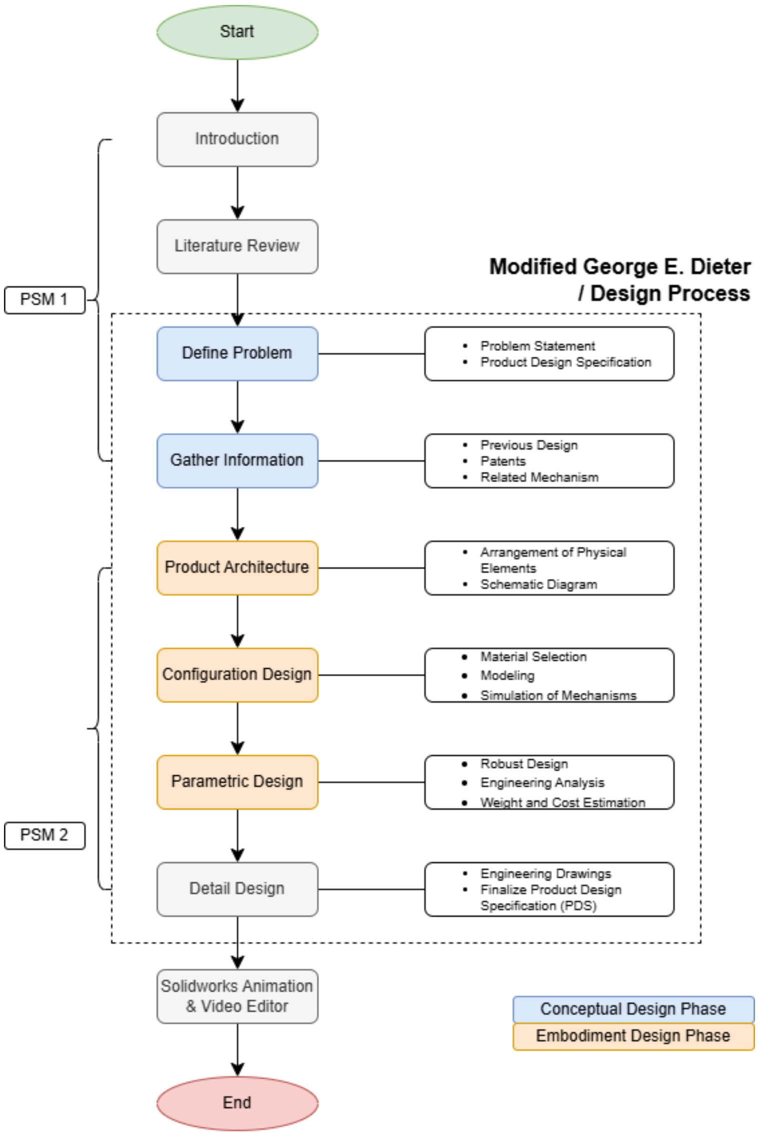


Fig.2 *Flowchart of Design Process [5]*

3. Design Process

The design process aims to guide students through a structured sequence of steps to solve a real-life challenge with an effective design solution. The design process begins with problem definition and concludes with functional animation. Because this project is an extension of previous work, the stages of concept generation and evaluation were excluded, as they had already been completed. The process focuses on refining existing components to meet specific client requirements regarding weight, power source, and operational efficiency.

3.1 Problem Definition and Specification

The primary task in the problem definition phase was identifying the clients' critical needs. The previous prototype faced significant limitations, including a total weight of 370.56 kg, which exceeded the 250 kg target, a lifting speed of only 0.78 m/s, which didn't meet the 1 m/s target, and reliance on electricity in plantation areas. To address these, a product design specification (PDS) was established to guide the improvement project, as shown in Table 1.

Table 1 *Product Design Specification*

Introduction	
Title	Improvement of The Palm Fruit Lifting Device for Trucks
Design Problem	The last designed lifting device had exceeded body weight and was inconvenient
Intended Purpose	To reduce the lifting device's body weight and improve its convenience, so that it can satisfy the needs of clients
Special Feature	Able to control the speed of the device Use the engine as a power source Use lightweight materials to reduce body weight Flexible design
Customer Requirements	
Functional Performance	The load capacity of a machine is above 100 kg The machine should be easy to maintain The lifting height of the product is above 2 m The design of the lifting device should be flexible for ease of storage and transport The use of an engine to operate the lifting device instead of a motor with a generator The speed of transferring palm fruit should be at least 1m/s
Design	The design should be straightforward and appealing, with an even finish that reflects the current market trend Portable The maximum body weight of the lifting device should not be more than 250 kg
Price	The selling price of the machine is below RM5,500 Low maintenance cost
Sustainable	Strong and sturdy Anti-corrosion Longer lifespan with more than 10 years
Operating Environment	Suitable for any type of road surface in the palm oil field
Geometric Limitation	The machine should be portable The machine does not use a large space to store
Maintenance, Repair, Retirement	The machine should have low maintenance and repair needed during its economic life Spare parts are easily accessible
Reliability, Robustness	No failure occurs during economic life All parts have high corrosion resistance The machine can withstand 6 hours per day of operation
Safety	The machine is stable and without any failures occurring during its economic life
Ergonomics	Easy to assemble and disassemble Easy to use User-friendly

3.2 Product Architecture

Product architecture is a crucial step in product development. It determines the physical components and structure required for the product to perform its intended tasks. The goal of product architecture is to organize functional components into clusters that make up the product's modules. The organization and interaction of the product's physical components are depicted in a schematic diagram, as shown in Fig. 3.

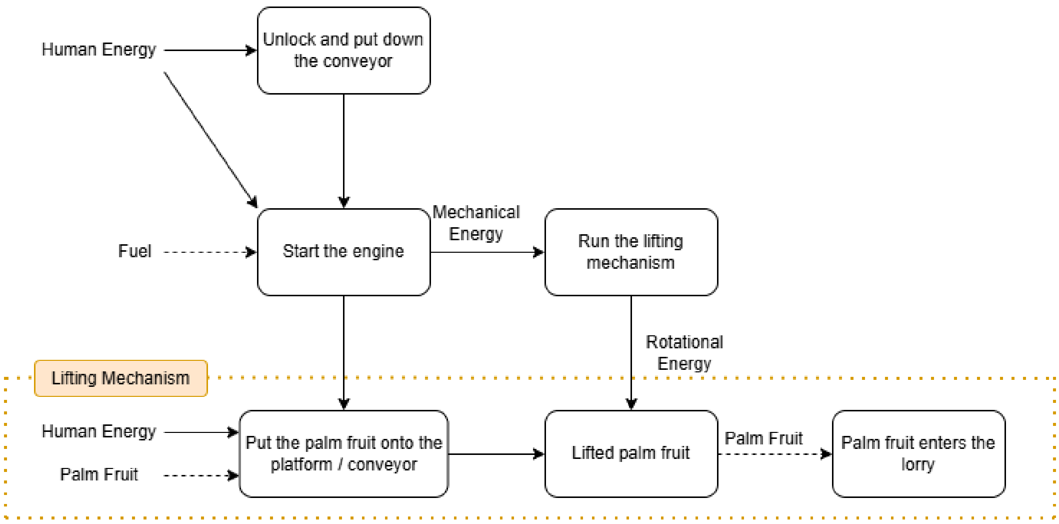


Fig.3 *Schematic Diagram with Clustered Elements*

3.3 Modelling

The 3D models of this lifting device were created in SolidWorks, a computer-aided design tool. The models were based on the previous design done by Wan Sayyidil Athir, and some modifications were made to achieve the goals. The model can be divided into five parts, including the main frame, which acts as the lifting path for the palm fruit to elevate and travel into the bed of the truck, a lifting mechanism that is driven with a sprocket and chain system to lift the palm fruits with the help of palm fruit holders attached to the chain, the power transmission system which was redesigned as a compact unit mounted under the truck chassis, a new holder arm mechanism utilizing an A-frame design allows the device to be securely attached to the truck and folded when not in use, and a new leg holders component which is welded on the back of the cargo as support and lock to the lifting device when folded and attached to the cargo when not in use. These components were then integrated to form the final product, which is a palm fruit lifting device. Fig. 4 shows the full assembly of the device in operational configuration, with labelling of the main components that make up the palm fruit lifting device.

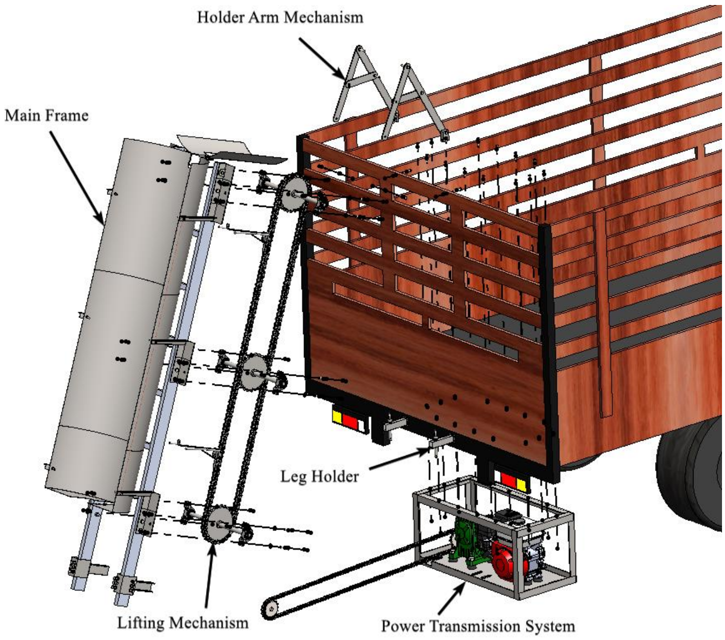
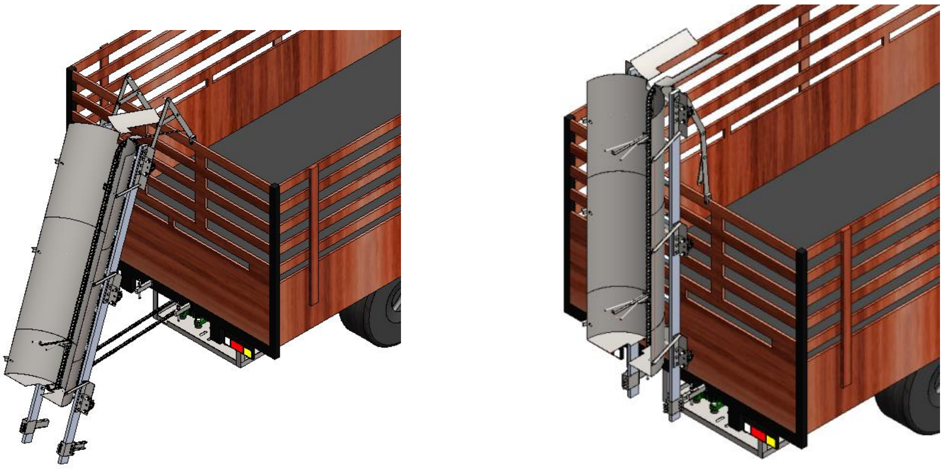


Fig.4 *Full Assembly of Palm Fruit Lifting Device with Labelling of the Main Components*

Fig. 5 below shows the different configurations of the palm fruit lifting device: Fig. 5(a) represents the configuration of the lifting device in operational condition, while Fig. 5(b) represents the configuration of the lifting device in rest or travelling condition.



(a) (b)

Fig.5 *Configuration of the Palm Fruit Lifting Device in (a)Operational Condition, (b)Travelling Condition*

3.4 Power Source

The power source, located beneath the truck chassis, uses a gasoline engine to drive the transmission chain via a worm-gear speed reducer. The engine rotates a driver pulley, which transmits motion to the gearbox's driven pulley via a V-belt. This configuration increases torque while decreasing the speed of the transmission sprocket. Finally, the main input sprocket at the base of the lifting mechanism receives this high-torque power directly from the chain to operate the system. Fig.6 illustrates the power transmission from the engine to the lifting sprocket.

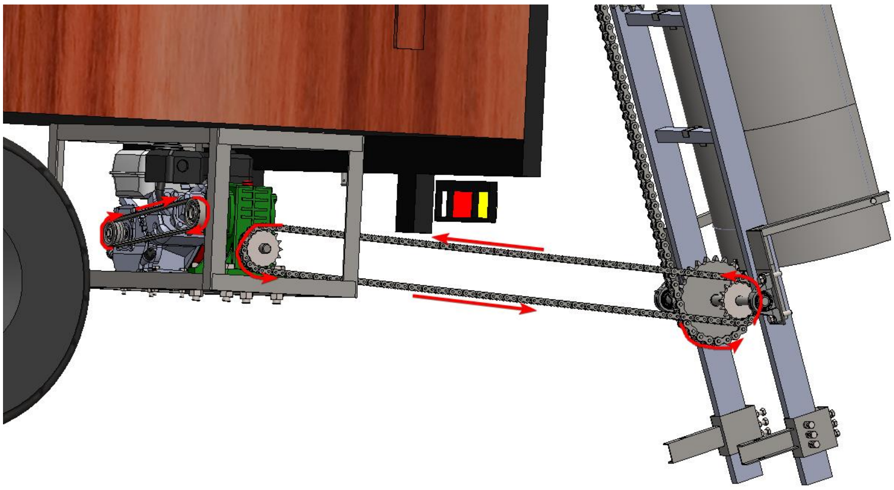


Fig. 6 *Power Transmission System of the Palm Fruit Lifting Device*

3.5 Lifting Mechanism

The system's lifting mechanism uses a chain-and-sprocket configuration to raise objects, such as palm fruit, from a lower to a higher level. The process starts at the base of the frame, where the fresh fruit bunches are placed in preparation for loading using a specialized platform installed there. The fruit is scooped from this platform onto an angled holder that rises along the conveyor path via the chain-and-sprocket mechanism's continuous operation. The fruit is automatically released into the truck bed by the circular momentum as the holder reaches the top of the frame. Fig. 7 illustrates the device's movement and operation for elevating palm fruit.

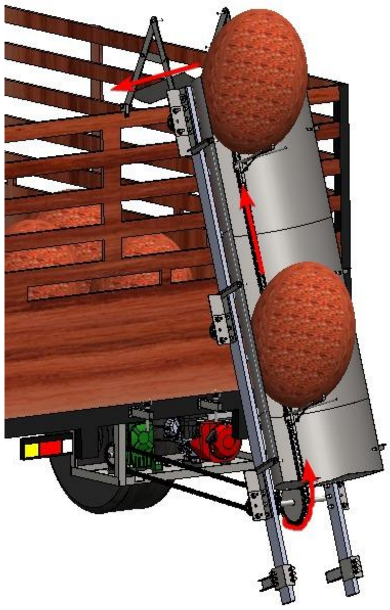


Fig. 7 *Lifting Mechanism of the Palm Fruit Lifting Device*

3.6 Engineering Analysis

Engineering analysis is a crucial process that verifies design concepts and minimizes the need for physical prototypes. To determine whether the design is appropriate, it is critical to analyze the important parameters of the system's components and standard parts. In the palm fruit lifting device, the power transmission system's energy is needed to operate the sprocket and chain. First, the torque required to lift the palm fruits is calculated:

$$\text{Torque Required, } T_{req} = F_{load} \text{ x } r \quad (1)$$

Calculate the total load first:

$$\text{Total Load Force, } F_{load} = \text{Total mass x g x sin } (\theta) \quad (2)$$
$$= 60 \text{ kg x } 9.81 \text{ m/s}^2 \text{ x sin } (70^{\circ})$$
$$= 553.1 \text{ N}$$

The pitch diameter of the sprocket 16B-1 25Z is 0.203 m, so:

$$\text{Torque Required, } T_{req} = F_{load} \text{ x } r$$
$$= 553.1 \text{ N x } \frac{0.203}{2} \, m$$
$$= 56.14 \text{ Nm}$$

Next, the power required to lift the palm fruits is calculated:

$$\text{Power Required, } P_{req} = \frac{F_{load} \, x \, V_{target}}{\eta_{engine}} \quad (3)$$
$$= \frac{553.1 \, x \, 1}{0.75}$$
$$= 737.47 \text{ W}$$
$$= 0.74 \text{ kW}$$

Based on the above calculation, the engine is selected with the parameters shown in Table 2.

Table 2 *Fixed Parameters of Engine*

Products	Fixed Parameters
Engine	Maximum output power: 3.7 kW / 4000 rpm Continuous output power: 2.6 kW / 3600 rpm Continuous output torque: 6.9 Nm / 3600 rpm Maximum torque: 9.3 Nm / 2800 rpm

Since the engine's parameters are not suitable for direct operation of the lifting mechanism, a reduction gearbox is required. To choose a suitable gearbox, a gear ratio is required. First, the gear ratio based on the speed is calculated. Since the target speed of the lifting mechanism is 1 m/s, the running revolutions per minute can be calculated based on the continuous output power of the engine:

$$\text{Velocity, } V = \frac{\pi \ x \ D \ x \ N}{60} \tag{4}$$

$$1 = \frac{\pi \ x \ 0.203 \ x \ N}{60}$$

$$N = 94.1 \text{ rpm}$$

Gear ratio based on the speed is:

$$\text{Gear Ratio} = 3600 / 94.1$$
$$= 38.26$$

Gear ratio based on the torque is:

$$\text{Gear Ratio} = 56.14 / 6.9$$
$$= 8.26$$

The suitable reduction gearbox is one with a gear ratio range of 8.26 to 38.26. Thus, a gearbox with a 1:20 gear ratio is chosen. The gearbox will be the first-stage ratio, while the pulley with a ratio of 2 will be the second-stage ratio, so the total ratio is 40.

By using the calculated ratio, the new output velocity and torque can be determined.

$$\text{New Output Velocity, } N_{gearbox} = \frac{N_{engine}}{ratio} \tag{5}$$

$$= \frac{3600}{20 \ x \ 2}$$

$$= 90 \text{ rpm}$$

$$\text{New Output Torque, } T_{gearbox} = T_{engine} \text{ x Pulley Ratio x Gearbox Ratio} \tag{6}$$
$$= 6.9 \text{ x } 2 \text{ x } 20$$
$$= 276 \text{ Nm}$$

The actual velocity of the lifting mechanism to lift the palm fruit is calculated:

$$\text{Actual Velocity, } V_{actual} = \frac{\pi \ x \ D \ x \ N_{shaft}}{60}$$

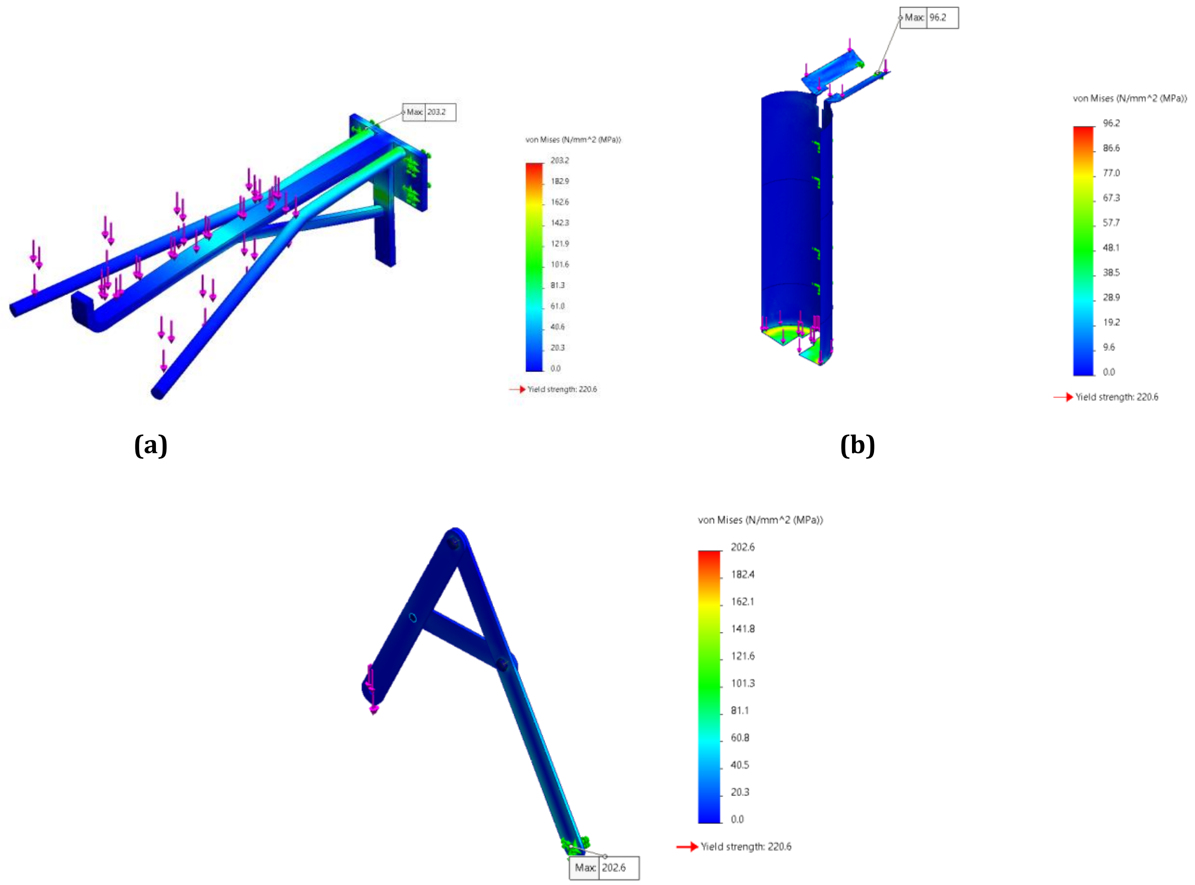
$$= \frac{\pi \ x \ 0.203 \ m \ x \ 90 \ rpm}{60}$$

$$= 0.96 \text{ m/s}$$

The actual velocity of the palm fruit lifting device is 0.96 m/s, which is very close to the client's target of 1 m/s and much better than the previous design's 0.78 m/s.

3.7 Simulation

SolidWorks simulation is essential for predicting a product's performance in real-life situations. Before a design is put into production, engineers can confirm that its durability, safety, and kinematic characteristics meet industry standards through static evaluations and Von Mises stress analysis. This virtual modelling method enables overcoming engineering challenges without the costs of physical prototyping, enabling thorough assessments of component lifespan and quality. There are three main structures involved in the simulation process, which these structures are directly related to the palm fruit lifting process. The three main structures include the palm fruit holder, which is used to carry the palm fruit bunches and travel into the truck, the drum, which is acting as the support and pathway to ensure that the palm fruit bunches lifting in position to prevent falling, and the holder arm mechanism, which acts as the support for the overall palm fruit lifting device during lifting process. Fig.8 below represents the simulations of the main structures, which are (a) palm fruit holder, (b) drum, and (c) holder arm mechanism.



(a) **(b)**

(c)

Fig. 8 *Simulation of (a)Palm Fruit Holder, (b)Drum, (c)Holder Arm Mechanism*

From the simulation results shown in Fig.8, it can be found that the Von Mises stress simulation for the palm fruit holder, the drum, and the holder arm mechanism indicate a peak stress of 203.2 MPa, 96.2 MPa, and 202.6 MPa respectively, and given that the material can possess a yield strength of 220.6 MPa, the maximum stress levels remain within the elastic (linear) range. This prevents permanent deformation by ensuring that, even if the material bends under load, it will revert to its original form once the load is removed. Besides that, the simulation results indicate that the safety factors for the main structures are greater than 1, validating the components' structural ability to support the desired load.

3.8 Detail Design

Product specifications serve as a fundamental roadmap, outlining the characteristics and requirements that must be met to guide development. Following these guidelines ensures the finished product meets industry quality standards and client requirements. Table 3 lists the precise specifications for the Palm Fruit Lifting Device.

Table 3 *Product Specification*

Detail	Product Specification
Load Capacity	60 kg
Dimension	1236 mm (W) x 2665 mm (H)
Lifting Speed	0.96 m/s
Operation Lifting Height	2.2 m
Manual Lifting Height	0.61 m
Weight	151.641 kg
Power	0.74 kW
Price	RM 5,154.08

4. Conclusion

The improvement project for the palm fruit lifting device successfully addressed the critical limitations identified in previous designs, thereby better serving the Malaysian oil palm sector. By utilizing a systematic engineering framework based on a modified George E. Dieter design process, the study achieved its primary objective of enhancing field adaptability and portability. The switch to a self-sufficient engine-driven power system, which enables the gadget to function in isolated plantation areas without a reliable electrical supply, was a significant accomplishment of this project. Additionally, prior problems with movement and storage in confined plantation spaces were fixed with the addition of a flexible, foldable A-frame construction and unique leg holders.

The design was further optimized for operational efficiency and weight reduction, achieving a target weight of under 250 kg, down from 370.56 kg. Through detailed engineering analysis and the integration of a refined power transmission system, comprising a gasoline engine, a 1:20 ratio gearbox, and a pulley system, the device achieved an actual lifting speed of 0.96 m/s. This performance significantly improves upon the earlier speed of 0.78 m/s and closely aligns with the industry target of 1.0 m/s. Ultimately, by resolving these ergonomic and technical challenges, the improved lifting device provides a practical, portable solution that reduces labor intensity and musculoskeletal risks for workers while enhancing productivity in actual plantation settings.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Martin Ling Teck Seng, Mohd Azwir Bin Azlan;* ***data collection:*** *Martin Ling Teck Seng;* ***analysis and interpretation of results:*** *Martin Ling Teck Seng, Mohd Azwir Bin Azlan, Shahrin Hisham Bin Amirnordin;* ***draft manuscript preparation:*** *Martin Ling Teck Seng, Mohd Azwir Bin Azlan, Ahmad Fu'ad Bin Idris. All authors reviewed the results and approved the final version of the manuscript.*

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