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Design of a scaffolding-assisted harvesting tool for palm fresh fruit bunch transport vehicles

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Abstract

The productivity and efficiency of oil palm harvesting are greatly influenced by the geographical conditions and soil structure of plantation areas, especially in regions with sloped and uneven terrain. In addition, the harvesting methods used also significantly affect the productivity and efficiency of the oil palm harvesting process. Conventional or manual harvesting methods that are still widely used, such as the use of egrek and dodos, often face limitations in terms of ergonomics, vertical access, time efficiency, and work safety, which ultimately reduce productivity and make the process less efficient. The development and design of scaffolding for Fresh Fruit Bunch (FFB) harvesting equipment aim to create an auxiliary tool that integrates a portable scaffolding system with an FFB transport vehicle. The design and development process begins with an analysis of the needs and problems encountered in actual field conditions. Based on these needs and challenges, a new innovation is required to improve the productivity and efficiency of FFB harvesting. The design utilizes three scaffolding frames capable of vertical movement through a hydraulic hoist system, sling, pulley, and bearings, which are designed to reach fresh fruit bunches at a height of approximately 7 meters. After the development and design stages are completed, structural analysis is performed using a finite element analysis (FEA) approach in SolidWorks software to determine stress distribution and deformation on each scaffolding frame under applied loads. The analysis results show that the maximum stress generated is far below the yield strength of AISI 1020 material (±350 MPa), with load distribution across the frames ranging from 716 N to 1283 N, indicating that the structure is categorized as safe. Additionally, the design scheme allows flexible assembly and loading of the scaffolding using a jack lift, enabling the vehicle to remain functional as a transportation unit or harvest carrier.

Keywords

Palm oil harvesting equipment, Scaffolding, Structural analysis

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Introduction

The palm oil industry is a strategic sector in the Indonesian economy as it contributes significantly to national foreign exchange earnings and employment absorption. One of the most critical stages in this industry is the harvesting process of Fresh Fruit Bunches (FFB), as it directly determines the quality and quantity of palm oil produced. However, field harvesting practices are still predominantly carried out using manual methods with conventional tools such as dodos and egrek. Land Conditions show in Figure 1.

Figure 1. Land Conditions

Manual harvesting methods have several limitations, including low time efficiency, a high risk of occupational accidents, limited vertical access to tall oil palm trees, and non-ergonomic workloads for workers show in Figure 2. These conditions are further exacerbated in plantation areas with uneven terrain and difficult accessibility. Therefore, technological innovations in the form of harvesting support equipment are required to improve the efficiency, safety, and productivity of Fresh Fruit Bunch (FFB) harvesting.

Figure 2. Oil palm fruits

This study aims to develop and design a portable scaffolding system integrated with a transport vehicle to provide safe and stable vertical access for operators during the Fresh Fruit Bunch (FFB) harvesting process. The design was carried out using a mechanical engineering approach that considers functional, structural, ergonomic, and occupational safety aspects.

Literature review

Fresh fruit bunches (FFB)

Fresh Fruit Bunches (FFB) are clusters of oil palm fruits that have reached an optimal level of maturity and are ready for harvesting. FFB consist of individual fruits composed of several layers, namely the exocarp, mesocarp, endocarp, and kernel. The primary oil content is found in the mesocarp and kernel; therefore, the degree of fruit maturity significantly affects oil yield.

Oil palm harvesting process

Oil palm harvesting involves cutting the fruit bunches, trimming obstructing fronds, collecting loose fruits, and transporting the harvest to the collection point. The success of the harvesting process is influenced by harvest maturity criteria, harvesting rotation, labor availability, and the transportation system.

Conventional harvesting tools

Conventional harvesting tools such as *dodos* and *egrek* are used based on the height of the oil palm trees show in Figure 3. *Dodos* are applied to trees with heights of less than 3 meters, while *egrek* are used for taller trees. The limitations of these tools lie in ergonomic issues, operator stability, and work efficiency.

Figure 3. Conventional harvesting process

Scaffolding

Scaffolding is a temporary structure that functions as a working platform at a certain height. In the context of this study, scaffolding is applied as a supporting system for Fresh Fruit Bunch (FFB) harvesting to provide safe, stable, and flexible vertical access. The scaffolding is designed with a steel frame structure capable of supporting the loads of operators, harvesting tools, and dynamic forces during the harvesting process.

Methods

The research method employed in this study is an engineering design approach, which consists of the following stages:

Problem identification

Analysis of Fresh Fruit Bunch (FFB) harvesting conditions in the field, including the limitations of conventional harvesting tools and the need for vertical access (Table 1).

Table 1. Identification of problems and requirements in the fresh fruit bunch (FFB) harvesting process

No	Problem	Technical / Functional Requirements
1	Dense and moist soil structure with sloping land contours.	A stable harvesting support tool that can be used across various land contours and soil moisture conditions.
2	Tree spacing of approximately 7–8 meters without vertical access.	A lightweight structural system that can be used between trees to provide vertical access.
3	High position of fruit bunches (8–12 meters).	A safe and efficient vertical reach assistance tool.
4	Non-ergonomic harvester working posture, increasing the risk of fatigue and injury.	A working platform that supports an ergonomic posture during harvesting.
5	Full dependence on manual tools (egrek and dodos) with limited precision.	Supporting tools or structural systems to improve control and precision in harvesting.

Conceptual design

The development of a scaffolding-based harvesting tool concept integrated with a transport vehicle, including the lifting mechanism and a modular frame system show in Figure 4.

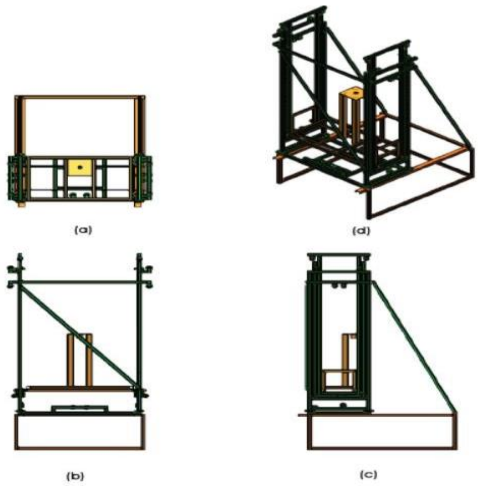

Figure 4. General overview of the harvesting scaffolding design: (a) Top view; (b) Front view; (c) Side view; (d) Isometric view

Detail design

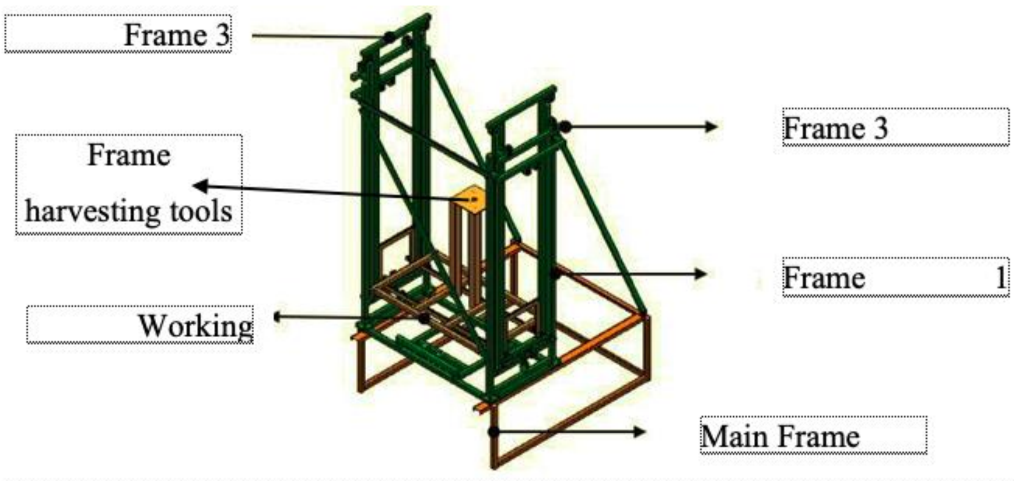

Figure 5. Detailed components of the scaffolding assembly

The development of three-dimensional models using Computer-Aided Design (CAD) software for all scaffolding components. The height and width dimensions of the main frame are 1248 x 1415 mm, frame 1 has dimensions of 2020 × 700 mm, frame 2 has dimensions of 1850 × 540 mm, frame 3 has dimensions of 2060 × 440 mm show in Figure 5.

Material selection

The primary material used is AISI 1020 carbon steel 1020 square tube 40 x 40 x 2,6 mm, selected based on its mechanical strength, availability, and ease of fabrication. Properties material AISI 1020 show in Table 2.

Table 2. Properties material AISI 1020

Property	Value	Unit
Elastic Modulus	200000000000	N/m^2
Poisson's Ratio	0.29	
Shear Modulus	77000000000	N/m^2
Mass Density	7900	Kg/m^3
Tensile Strength	420507000	N/m^2
Yield Strength	351571000	N/m^2

Structural analysis

Structural strength analysis was conducted using the Finite Element Analysis (FEA) method to determine stress distribution, deformation, and safety factors under working loads. The structural frame to be analyzed has the following dimensions 1470x700x2436 mm. The load applied to the frame is 170 kg. The structural frame to be analyzed show in Figure 6.

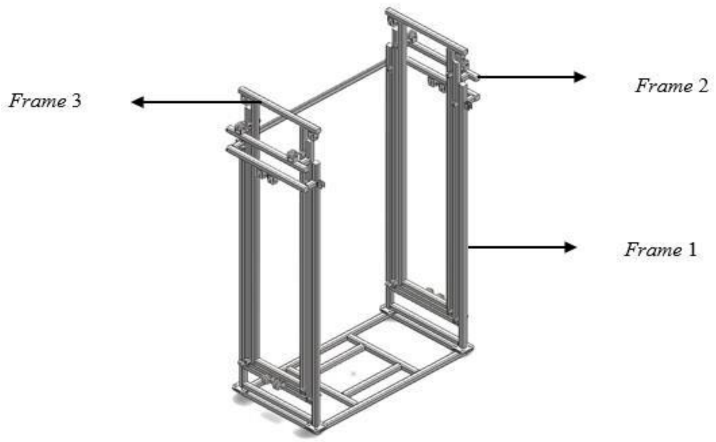

Figure 6. The structural frame to be analyzed

Design evaluation

The analysis results were used to refine and improve the design to ensure compliance with safety standards and operational performance requirements.

Results and discussion

Based on the simulation results using the Finite Element Analysis (FEA) method using CAE, the Von Mises stress distribution on the designed scaffolding structure was obtained. This simulation was conducted to predict the magnitude of stress acting on each frame element when the system is subjected to actual working loads during the

Fresh Fruit Bunch (FFB) harvesting process. Figure 6 shows that each frame in the scaffolding system experiences different load levels depending on its position and its contribution to the overall structural stability. Specifically, Frame 1 experiences the highest load, approximately 1283 N, which originates from the working platform and the direct effects of the operator's weight, harvesting tools, as well as the loads transferred from Frames 2 and 3. Frame 2 sustains a load of approximately 877 N, primarily resulting from inter-segment pressure caused by upward and downward movements, in addition to the load transmitted from Frame 3. Frame 3 experiences the lowest load, approximately 716 N, as it functions only as the uppermost segment that distributes forces downward and does not directly support the operator. The simulation results indicate that the maximum stress occurring in the scaffolding structure is significantly below the yield strength of AISI 1020 steel. Furthermore, the total deformation remains within safe limits, indicating that the structure does not undergo elastic failure. Von mises stress simulation results of the scaffolding frame show in Table 3.

Table 3. Von mises stress simulation results of the scaffolding frame

Maximum Stress Von Misses	Factor Of Safety
15324027 N/m^2	22,87

The design results indicate that the scaffolding system consists of three main frames capable of vertical movement using a hydraulic hoist system, slings, pulleys, and bearings. The system is designed to reach a height of up to approximately 7 meters, in accordance with the height of productive oil palm trees, and the scaffolding design is modular in nature. Results of static von mises stress analysis Figure 7.

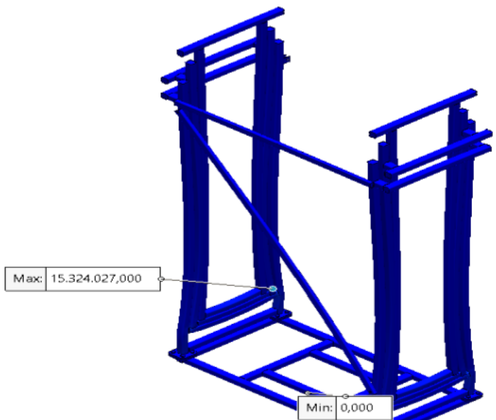

Figure 7. Results of static von mises stress analysis

Conclusion

Based on the research and design process conducted, it can be concluded that the proposed scaffolding system effectively enhances accessibility and safety during the Fresh Fruit Bunch (FFB) harvesting process, particularly for oil palm trees that are difficult to reach using conventional manual methods. The structural analysis demonstrated that the scaffolding design is safe for operation, as the resulting stress and deformation values remain within the allowable limits of the selected material.

Furthermore, the integration of the scaffolding system with a transport vehicle provides greater operational flexibility and improves the efficiency of both harvesting and transportation activities. Overall, the developed scaffolding-based harvesting tool shows strong potential to increase worker productivity, reduce occupational accident risks, and contribute to the long-term sustainability of the palm oil industry.

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