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Development of a Mini Crane for Lightweight Lifting Applications

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Abstract

Conventional cranes are often bulky and difficult to be operated in confined spaces, thus the demand for a more compact and safe lifting solution is rising. The main objectives of this study are to design, analyze, and fabricate a portable compact crane to improve safety and easy to be operated. The crane was first conceptually designed and modeled using SolidWorks 2021 and the structural performance was then evaluated through finite element simulation to determine the stress distribution, displacement, and strain under maximum operating load. The results showed that the maximum stress, displacement, and strain fall within the acceptable limits of mild steel. A prototype was then fabricated using standard manufacturing processes, such as cutting, drilling, welding, and mechanical fastening, before undergoing performance testing. The test demonstrated that the mini crane was able to lift and lower up to 188 kg loads with a maximum lifting height of 1700 mm and an adjustable reach between 1200 mm and 1400 mm. Overall, the mini crane offers a practical and affordable lifting solution for restrictive environments, thus improving safety and mobility compared to conventional cranes.

1. Introduction

In construction and lifting industries, mechanized solutions have replaced manual handling of heavy loads due to the high risks of injury and inefficient operation. As these industries continue to grow, the demand for transporting heavy loads in complex environments has also increased [1], [2]. One of the most widely used machines to lift, lower and move heavy materials across construction sites is the crane [3], [4]. A crane is generally equipped with a hoist, wire ropes, and sheaves to transport heavy loads easily [5].

In recent years, hydraulic mini cranes have been used to transport heavy loads in small industries and households safely and economically. These cranes are usually compact and can be easily maneuvered in restricted spaces where large cranes cannot enter. For instance, 'spider cranes' and 'spider kits' are commonly used as structural components in building facades and glazing systems because their compact shape allows them to fit through most doors and access areas inaccessible to standard cranes [6], [7]. Beyond the construction field, mini cranes have also been used for agricultural purposes, such as speeding up the loading of fresh fruit bunches to reduce fruit damage [8]. In addition, semi-automatic mini cranes have also been designed to help in loading and unloading spare tires into car boots [9].

A mini hydraulic crane is typically designed by combining several main components: the hydraulic actuator, boom, vertical column, crane hook, base plate, and fluid reservoir [10]. Material selection in the fabrication of a mini crane is vital to ensure the performance of the crane and to guarantee the safety of the user, where research has indicated that high strength materials, such as steel AISI 4340, provide optimum conditions for the crane frame [11]. Some authors also highlighted the feasibility of high strength S890 as jib joint frame of wheeled crane [12]. Additionally, modern designs also incorporate advanced sensors such as the HX711 as a control regulator to provide real time weight feedback and prevent motor damage due to overloading [13].

Hydraulic systems generates large amounts of force through pressurized fluid to lift heavy loads with relatively low input energy compared to mechanical or electrical systems. Recently, some industries focused on digital hydraulic valves and high precision control mechanisms for hydraulic robotic manipulators, however, these systems pose control challenges due to their structural complexity and nonlinear fluid dynamics. Therefore, the lifting industries have introduced nonlinear model predictive control (NMPC) to help improve trajectory tracking and automation [14].

Despite the technological advancements, safety remains the most critical aspect of crane operations, particularly for high altitude tasks where potential hazards such as falls from height, equipment malfunctions, and exposure to hazardous chemicals exist. Therefore, effective safety management and risk assessment are crucial to reduce accident rates in construction sites [15], [16]. Besides, the ergonomic aspect of mini cranes is also taken into consideration, allowing nonprofessional users to operate the equipment without specialized skills and extending their application in smaller workspaces.

However, many of these modern systems require complex setups, continuous electrical supplies, and high manufacturing costs, making them less practical for smaller scale or budget constrained applications. Also, the development of purely mechanical, highly ergonomic, and fully foldable mini cranes that are portable at a low initial cost without sacrificing structural integrity remains notably lacking. Therefore, this study aims to design, analyze, and fabricate a portable mini crane equipped with a foldable mechanism that is suitable for workshops and households. The scope of this study is limited to hydraulic systems using lightweight but high strength materials to achieve significant lifting capacities. The novelty of this work lies in the structural optimization of its foldable base legs by allowing the crane to be stored efficiently when not in use. Ultimately, this project has the potential to improve small scale material handling operations by offering a reliable and user friendly equipment that reduces manual labor, improves productivity, and meets workplace safety standards.

2. Methodology

The mini crane was developed using a structured design approach as shown in Fig.1. The process began with problem identification and generation of conceptual sketches. These designs were compared and evaluated to select the most suitable one. The finalized design was modeled into a 3D computer-aided design (CAD) using SolidWorks 2021, where individual parts were modeled with specific dimensions and materials. Prior to fabrication, the CAD model was subjected to structural strength analysis to verify its operational reliability. Upon successful validation through simulation, the physical prototype was fabricated using standard manufacturing processes. Prior to fabrication, the structural strength of the CAD model was analyzed to verify its reliability under operating loads. Once the simulation results were satisfactory, the physical prototype was fabricated using standard manufacturing processes and subsequently tested to verify its reliability.

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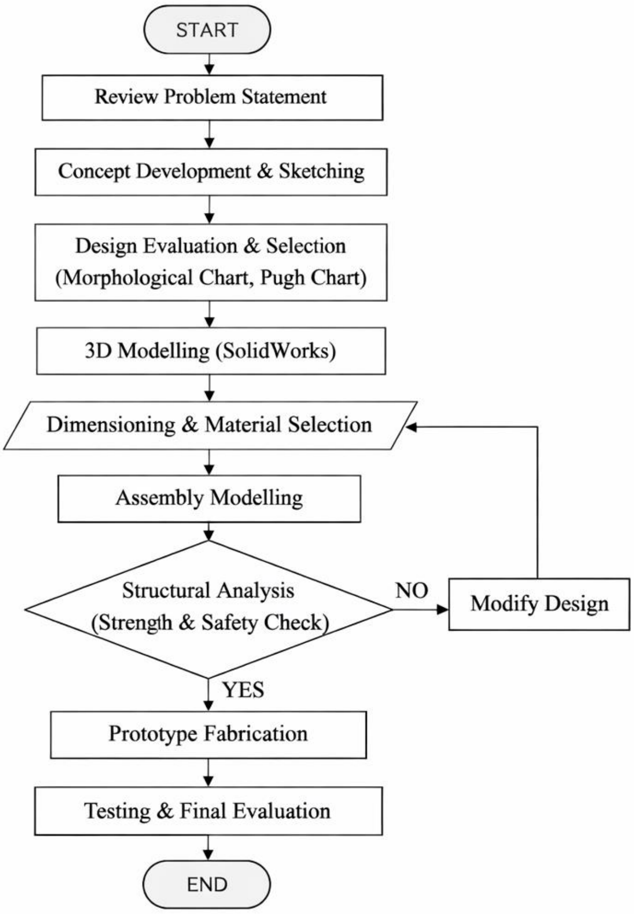

Fig. 1 *Project flowchart*

2.1 Detailed Design and CAD Modelling

The crane was modeled in SolidWorks 2021 using a bottom-up assembly approach where the individual parts were initially modeled separately using accurate dimensions before assembled together. The main structure consists of several parts working together.

The boom system consists of an outer and inner boom with multiple adjustment holes spaced at 100 mm intervals for adjustable lifting reach. The system was supported by a main vertical frame that acts as a load-bearing column and further supported by additional structural members to keep it stable and reduce bending under heavy loads. Lastly, the base structure completes the assembly. The structure is made up of a bottom frame, bottom support, and folding legs to allow the crane to be stored compactly when not in use.

The individual parts were then assembled, and mechanical mating constraints such as concentric, coincident, and parallel mates were also applied to replicate the actual mechanical connections of the welded joints, the slider mechanism of the boom, and the bolted joints of the foldable legs.

2.2 Detailed Design and CAD Modelling

A static structural analysis was conducted using the SolidWorks Simulation solver to evaluate the structural integrity of the mini crane model under operational load. The analysis was based on the loading conditions and theoretical calculations derived from the free body diagram of the crane boom.

Mild Steel and Aluminium Alloy were compared to determine the best material for the crane's structure because of their affordability and good strength. For the mesh Scheme, a solid high quality tetrahedral mesh was applied over the CAD model, and mesh refinement was applied at the pin slots, mounting brackets, and foldable leg joints where stress tends to concentrate. In terms of boundary condition, the bottom frame was fixed in place to simulate contact with the ground and prevent all translational and rotational degrees of freedom. This assumption was made to replicate the actual operating condition where the crane sits rigidly supported on the ground during lifting, allowing the load to be transferred from the boom through the frame down to the base. As for the loading conditions, a static downward force of 1.85 kN was applied at the tip of the inner boom to represent the maximum safe lifting load of 188 kg as determined from static equilibrium calculations. Under this load, the boom bends like a cantilever while the frame and base resist the induced moments and shear forces.

2.3 Fabrication and Performance Testing

The physical prototype was fabricated following standard manufacturing operations to achieve accurate dimensions and ensure the crane functions reliably. As safety precautions, personal protective equipment (PPE) was always worn to prevent workplace injuries. The fabrication process was conducted in six stages, starting with measuring and marking, where the mild steel hollow sections were measured and marked based on the CAD drawings. The square hollow sections of the outer boom, vertical frame, and bottom frame were marked using a scriber at 63.5 mm x 63.5 mm, while the inner boom was marked at 50.8 mm x 50.8 mm. A steel ruler and measuring tape were used to ensure dimensional precision of at least ±0.5 mm accuracy. A center punch was applied to mark hole positions for the boom adjustment mechanism and foldable legs to ensure accurate drill positioning and prevent drill bit wandering.

The marked mild steels were then cut into required lengths according to component specifications using a power cut off machine operating at approximately 3000-3500 rpm as shwon in Fig 2a. The vertical frame was cut to approximately 1500 mm in length, while the base supports and outer legs were cut to 800 mm to 1400 mm while, the smaller part of the structure such as support members and leg sections were shaped using a hand grinder as shown in Fig. 2b. For safety precautions, appropriate PPE was worn, including safety goggles, cut resistant gloves, ear protection, and safety boots. During cutting, a proper clamping of the workpiece was ensured to prevent movement during cutting, and sparks were controlled by maintaining a safe working distance of at least half a meter from the cutting point.

(a)

(b)

Fig. 2 *Cutting of the mild steel components using (a) Cut off machine; (b) Hand grinder*

Holes were subsequently drilled using a bench drilling machine at a spindle speed of 500 to 1500 rpm, depending on the bit diameter. High speed steel (HSS) drill bits of approximately 10 mm diameter were used to drill M10 bolts particularly in the boom for length adjustment, inner and outer legs for the folding mechanism, and some support connections. Besides, proper alignment and clamping were thoroughly stressed to achieve perpendicular and accurate hole formation. The edges were then smoothed using an angle grinder operating at 10,000-12,000 rpm with 5 inch abrasive discs to remove burrs and irregularities to reduce stress concentration areas.

The fabricated components were then assembled into a complete structure using two joining methods, namely Shielded Metal Arc Welding (SMAW) for primary load-bearing joints, particularly at the connection between the vertical frame, bottom frame, and support members, using a low voltage ranging from 30 to 40 V to form fillet welds for deeper penetration in the thick mild steel sections under high stress. During the welding process, a welding helmet, heat-resistant gloves, and safety boots were worn, and adequate ventilation was ensured to avoid inhaling harmful fumes. The movable and non permanent joints on the boom extension and foldable legs were assembled using M10 x 100 mm bolts, along with the pulley system and winch, which were mounted using bolts and brackets.

Finally, all weld joints were inspected for any cracks or incomplete fusion, and all the bolts were properly tightened. The fabricated crane was then coated with anti-corrosion primer and paint to protect the surface from corrosion and wear.

3. Results and Discussions

3.1 CAD Design and Model

The completed 3D CAD model of the mini crane, modeled using mild steel, is shown in Fig. 3, with the component dimensions summarized in Table 1.

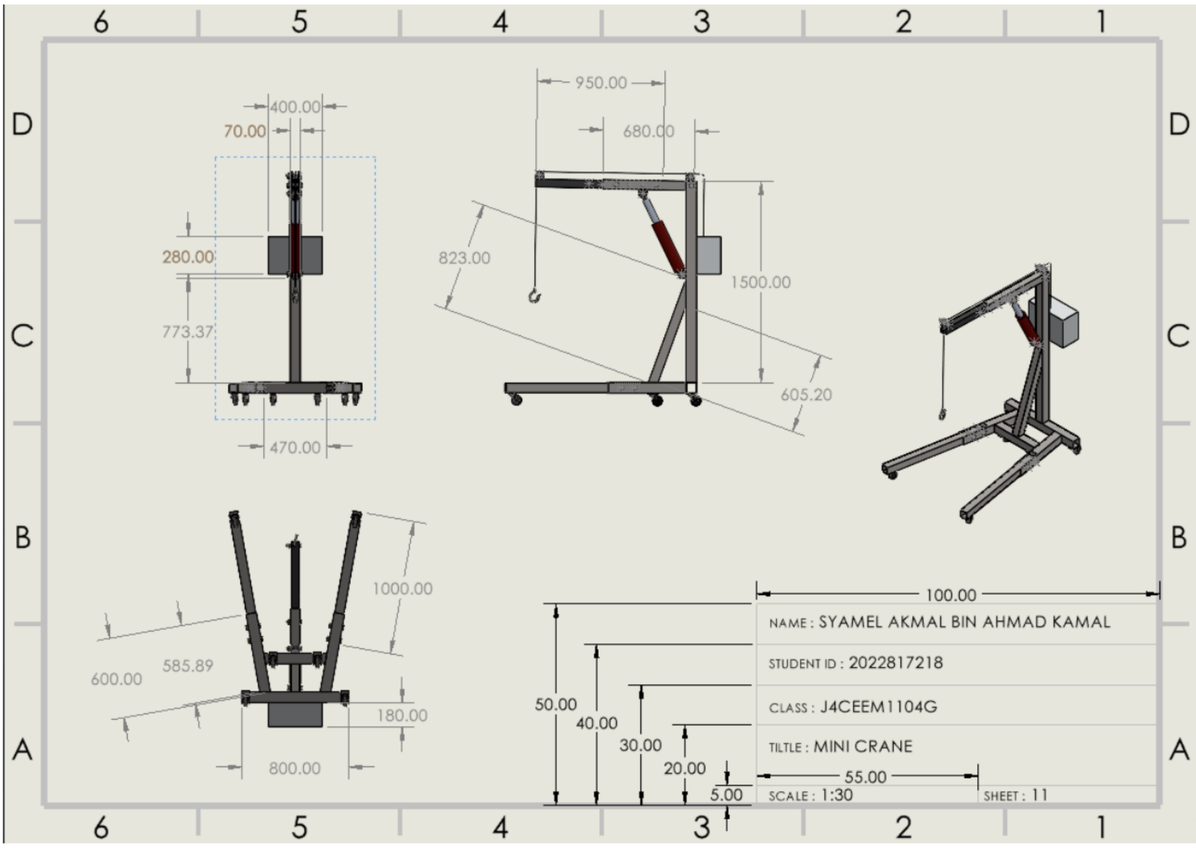

Fig. 3 *The assembly drawing of mini crane consisting of boom systems, vertical frames, base structures and support members*

Table 1 *Summary of CAD part drawings developed in SolidWorks 2021*

Component name	Key dimension	Cross-section
Outer boom	700 mm (L)	63.5 × 63.5 mm hollow
Inner boom	950 mm (L)	50.8 × 50.8 mm hollow
Vertical frame	1500 mm (H)	80 × 80 mm hollow
Bottom frame	800 mm (L)	80 × 70 mm hollow
Vertical support	823 mm (L)	70 × 60 mm hollow
Bottom support	470 mm (L)	80 × 70 mm hollow
Outer leg (right)	600 mm (L)	70 × 80 mm hollow
Outer leg (left)	600 mm (L)	70 × 80 mm hollow
Inner leg (right)	980 mm (L)	60 × 70 mm hollow
Inner leg (left)	980 mm (L)	60 x 70 mm hollow

3.2 Structural Analysis Using SolidWorks Simulation

As shown in Fig. 4, the stress distribution under a 188 kg load on the inner boom indicates the maximum von Mises stress remained below the yield strength (250 MPa) and ultimate tensile strength (400 MPa) of mild steel, thus showing that the boom will not fracture under the maximum load. Besides, Fig. 4 shows that the maximum nodal displacement at the free end of the boom was 2.975 mm, showing that the boom maintains its shape within acceptable limits during operation. The maximum principal strain of 2.651×10^{-4} was concentrated at the fixed end of the boom, behaving like a cantilever, and falls within the elastic range of mild steel, confirming that the design is safe. In structural design, maintaining the von Mises stress below the material yield strength ensures that the component operates within the elastic region and prevents permanent deformation under the applied loading [17], [18]. Furthermore, the small displacement and strain values indicate adequate structural strength, which is critical for maintaining the reliability of the boom during lifting operations.

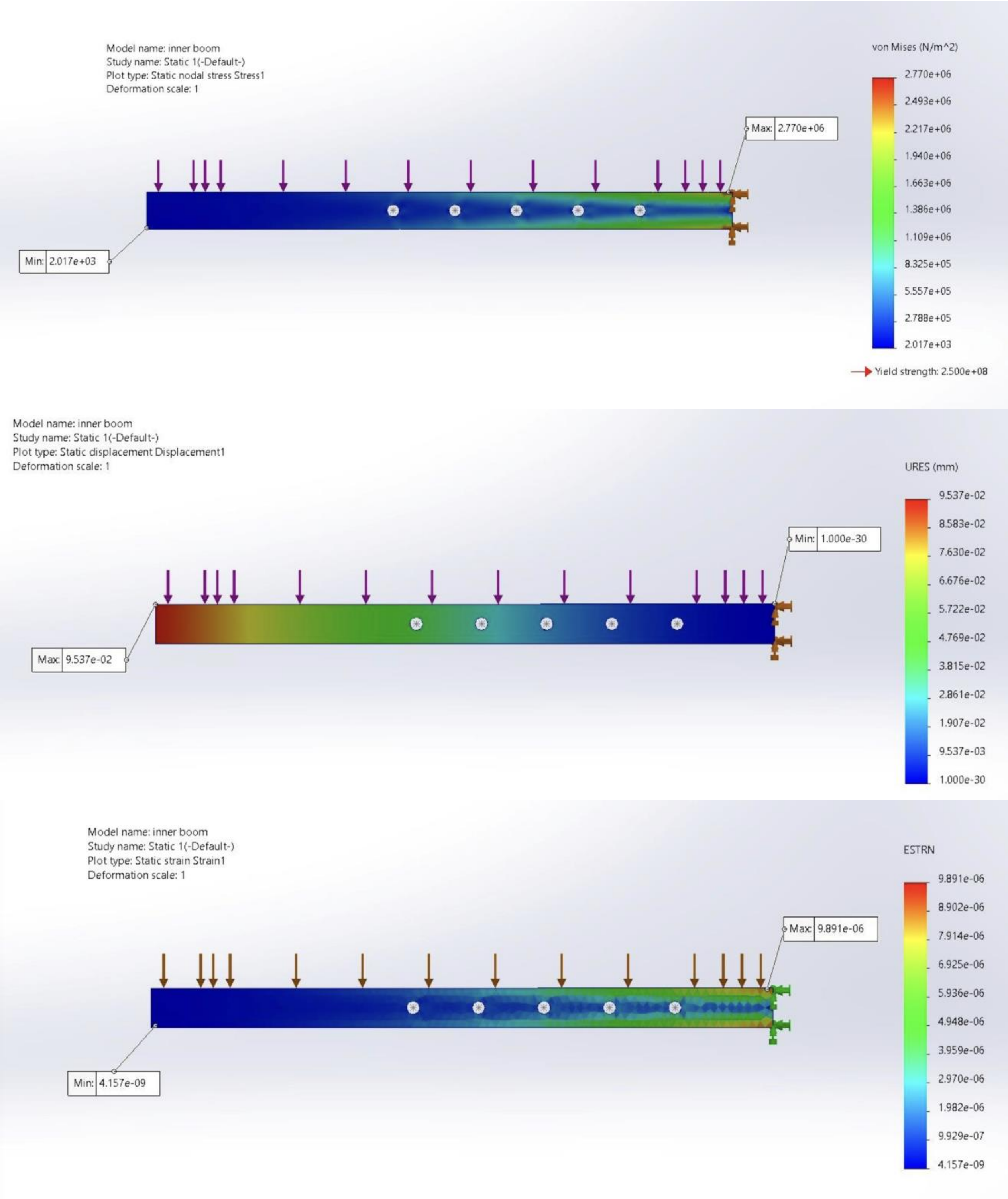

Fig. 4 *The structural analysis of the inner boom of the mini crane under a 188 kg load yields von Mises stress distribution (top), displacement (middle), and strain (bottom)*

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3.3 Fabricated Prototype and Functionality

The fabricated mini crane is shown in Fig. 5, and its final specifications are tabulated in Table 2. During physical testing, two main mechanisms were observed and validated; the lifting mechanism and mobility mechanism. For the lifting mechanism, the inner boom can be extended to adjust the horizontal reach of 1200 mm and 1400 mm and can be secured safely using M10 bolts. The manual winch controls the hook height by rotating the handle clockwise to lower and counterclockwise to lift the load, while the hydraulic jack provides additional vertical lift by raising the boom assembly to a maximum lifting height of 1700 mm.

As for the mobility mechanism, the crane sits on six rubber tyred wheels (40 mm x 46 mm x 64 mm) that allow it to be manually moved across flat surfaces. Additionally, a brake mechanism was used to lock the crane in place during lifting. Besides, the folding legs can also be retraced by removing the bolts to allow the crane to be stored compactly when not in use. The incorporation of folding legs has become a common feature in modern cranes, as this feature is particularly beneficial in workshops and facilities with limited floor space, where equipment must be easily stored and transported without compromising structural stability during operation [19], [20].

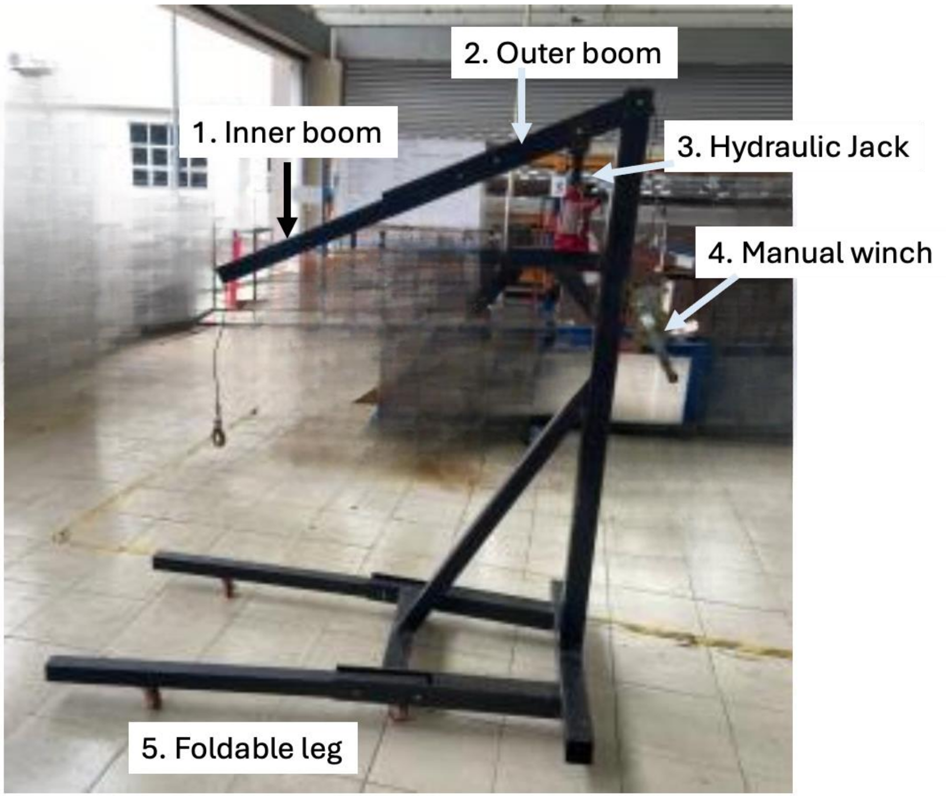

Fig. 5 *The fabricated prototype mini crane*

Table 2 *The final product specification of the mini crane prototype*

Specification	Description
Material	Mild steel (hollow square section)
Overall dimension	L (1400 mm) × W (900 mm) × H (1500 mm)
Maximum load capacity	188 kg (theoretical)
Tested load capacity	50 kg
Maximum lifting height	1700 mm
Horizontal reach	1200 mm – 1400 mm
Lifting mechanism	Manual winch and hydraulic jack (2 ton)
Mobility	6 rubber tyred wheels with integrated brakes
Joining method	SMAW welding + M10 mechanical fasteners

4. Conclusions

This study successfully designed, analyzed, and fabricated a mini crane for compact and light duty material handling applications. The structural performance was evaluated through analytical calculations and finite element simulation, where the results indicated that the maximum stress remained below the yield strength of mild steel. The simulation results proved that the designed mini crane is reliable and will not yield under maximum operating load and exhibited good agreement with the fabricated prototype, with minor modifications made due to material availability and cost constraints. The physical performance testing confirmed that the mini crane is able to lift a load of up to 188 kg. It is also able to extend vertically at a height of 1700 mm and is horizontally adjustable between 1200 mm and 1400 mm.

In conclusion, the fabricated mini cranes are practical to solve for material handling in restricted spaces for lightweight applications. It also enhances safety and efficiency compared to manual lifting methods, with ease of portability and operation. However, some limitations of the fabricated prototype include limited load capacity and unstability on uneven ground. In the future, some improvements are recommended, such as improving the structural strength, increasing the load capacity, and incorporating automated lifting mechanisms to make the crane more capable and easier to use.

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Conflict of Interest

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

Author Contribution

The authors confirm their contributions to the paper as follows: ***conceptualization and methodology:*** *Syamel Akmal Bin Ahmad Kamal;* ***investigation, data curation, and formal analysis****: Syamel Akmal Bin Ahmad Kamal;* ***fabrication and original draft preparation****: Syamel Akmal Bin Ahmad Kamal;* ***supervision, validation, and project administration****: Nur Aini Sabrin Binti Manssor;* ***resources and validation****: Nurrul Amilin Binti Zainal Abidin, Nurul Hanna Binti Mas'aud. All authors were involved in reviewing and editing the manuscript and approved the final version.*

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