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INNOVATIVE DESIGN AND ANALYSIS OF THE AI-POWERED GUARDIAN LAWN MOWER

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ABSTRACT

The project presents " Innovative Design and Analysis of the Guardian Lawn Mower with artificial intelligence". Major advances in lawn care and home security. It includes the development of various lawnmowers designed to operate in intelligent, automatic, semi-automatic, and manual modes. The mower features independent suspension wheels, a sturdy frame with a capacity of over 100 kg, and a solar panel for natural batteries. The system includes a powerful internal generator for accurate grass collection and a lidar sensor for precise navigation and visual impact, including identifying objects and people. Sound sirens and cameras installed in the house increase home security by capturing images of strangers and sending instant notifications to phones. This project uses a Jetson Nano for operation, a Raspberry Pi for control, and a motor to independently control each wheel. Design and review using SolidWorks and ANSYS to ensure model integrity and functionality. The program not only improves lawnmower technology but also includes home security measures to meet the needs of today's society better.

INTRODUCTION

Automation and AI technology have penetrated many aspects of life, whether at work or in everyday life. Even a labor-intensive activity such as mowing a lawn has enjoyed advancements thanks to autonomous devices that aim to minimize effort and time consumption. However, in big residential and commercial areas, normal mowers are too slow and inaccurate, cannot perform big-scale tasks, and are inflexible in operations. Apart from that, there is a growing need for multipurpose devices by consumers who are concerned with home safety.

The project aims to add AI-integrated automation into mowing lawns, improving the efficiency of the operations while adding security features as well. It provides a solution that fuses an autonomous and flexible mowing system with monitoring and security features. Such elements help avoid conflicts arising from outdoor lawn maintenance and the security of the house or business premises. In this integrated system, the twin problems of maintaining the lawn and safeguarding the property are effectively addressed, which is very welcoming for the needs of home and commercial property owners.

2. Literature Survey

Akash Chaudhary Raghuvanshi et al. (2015) [1] designed a foldable go-kart named 'ASHVA'. The kart can be folded at its midsection. ANSYS software was used to analyze the strength of the joint. SS-202 stainless steel was selected for chassis material. The kart achieves a speed of 52 km/hr. The design is inspired by a fish body's aerodynamics. The joint supports both chassis and bears maximum force.

Naveen Kumar Chandramohan et al. (2020) [2] developed an IC engine Go-kart that was converted to electric power. Frame modifications were necessary to accommodate electric components. An Electric Go-kart frame showed greater weight than IC powered frame. Deformation was less in IC-powered Go-karts during impacts. Electric Go-kart frame design proved safe with an FOS of nearly 2.

Jay Prakash Srivastava et al. (2020) [3] stated that the AISI 1020 material is optimal for the Go Kart roll-cage. A thickness of 1.4 mm provides the best strength and safety. Increased thickness reduces von Mises stress and deformation. Higher thickness leads to heavier vehicles and increased costs. 48 finite element analyses were conducted for impact assessments. Study aids in safer and affordable Go-Kart production.

Anas Mohammed. N et al. (2018) [4] reported that chassis design is safe with a maximum stress of 235 MPa. The maximum deflection of the chassis is 1.3 mm. The natural frequency of the chassis is 155 Hz. Vibrational characteristics were determined using transient analysis. The expected life of the chassis was assessed through fatigue analysis. Vibration transfer path analysis identified weak points in the chassis.

Yuwana Sanjaya et al. (2021) [5] analyzed different mesh sizes to yield varying simulation results. Optimal mesh size is crucial for accurate analysis. 10 mm mesh size shows the closest results in simulations. Error ratios for displacement and stress were calculated. Convergence is achieved through the comparison of mesh sizes.

Ashwini Biradar et al. (2021) [6] designed shock absorbers for off-road race cars. Alloy steel (ASTM A231) was selected for the spring material. The weight of the spring was reduced from 1.551 kg to 0.532 kg. Stress and deformation values within permissible limits. 3D modeling was done using CATIA V5 software. Structural analysis was performed using ANSYS software. Optimized performance was achieved by changing the wire diameter to 7 mm.

Akriti Vashist et al. [7] stated that the suspension system design maximizes damping and minimizes track width change. Optimized suspension parameters improve geometry and component design. The factor of safety values is suitable for real-time applications. The final design achieved optimum suspension angles and bump steer results. The ATV ranked 18th overall in the BAJA SAE India event.

Sangeetha Krishnamoorthi et al. (2020) [8] designed an Electric Go Kart without suspension and differential. AISI 1018 is optimal for chassis material. 3D modeling was done using SolidWorks 2020. Analysis performed using ANSYS 2019 R2. Achieved a speed of 60 km/h safely. Ackerman steering mechanism selected for better handling. The caster angle is set at 12° and the kingpin at 7°. The electric motor used is a 2000-watt, 48 V Brushless DC. Future designs may utilize enhanced composite materials.

Meenatchisundaram et al. (2022) [9] developed a semi-automated lawnmower for commercial use. The device operates via an Android application, reducing labor needs. It is lightweight and made from UPVC material. The system relies on a traditional battery for power supply. Mass production is cost-efficient and easy to maintain. It requires no special skills for operation. The lawnmower is suitable for various public locations. Material selection considers physical and mechanical properties. The fabrication process involves precise cutting and assembly of UPVC pipes.

L. Bertini et al. (2017) [10] designed a finite element model that predicts HPT blade creep behavior. Flight data records provided thermal and mechanical data for analysis. 3D model created from scanned HPT blade scrap. Simulations showed expected displacement behavior at the blade's trailing edge. The model aids in predicting turbine blade life using FDR data.

Olawale Olaniyi Emmanuel AJIBOLA et al. (2021) [11] designed a constructed an automated lawn mower that was successful. The mower operates with minimal human intervention and fatigue. It utilizes solar energy and an AC supply for charging. The device features proximity sensors for object detection. It can function in semi-autonomous and fully autonomous modes. The mower has low running costs and minimal noise pollution. It does not require perimeter wires for operation. The device is eco-friendly with no harmful effects on users. The only imperfection noted was in high grass-density areas.

Ashish Kumar Chaudhari et al. (2016) [12] designed automated grass trimming using a solar-powered robot. It reduces human effort and energy consumption in mowing. The device uses an IR sensor to detect obstacles. The system includes a battery charged by solar panels. It features adjustable cutting height via a link mechanism.

Bidgar Pravin Dilip et al. (2017) [13] fabricated automatic solar grass cutters to reduce pollution and energy loss. It operates using solar power and various sensors. The design includes a microcontroller and LCD. It serves residences where tractor-mowers are impractical. The machine is a viable alternative to gasoline mowers. It requires less maintenance compared to conventional mowers. The system is efficient and operates with minimal effort.

Mothukuri Shiva Chander et al. (2020) [14] designed an Agri-cutter for efficient crop slicing. The machine reduces human effort in sugarcane harvesting. It utilizes a four-bar linkage mechanism for operation. The design is suitable for small-scale farmers. The machine operates on a DC motor and solar power. Performance evaluation showed faster cutting rates than manual methods. Future improvements include automated feeding and enhanced blade design.

Rubentheran Sivagurunathan et al. (2017) [15] designed a portable lawn mower and fabricated it. The mower operates on a rechargeable battery. It achieves a rotational speed of 19,300 RPM. The design focuses on lightweight and durability. Fabrication costs are significantly lower than commercial mowers. It supports eco-friendly and green technology initiatives.

Ilesanmi Daniyan et al. (2020) [16] designed a robot that autonomously mows lawns with high efficiency. It avoids obstacles using GPS and sensors. The robot can make 180-degree turns. It operates with minimal human intervention. The design allows for straight parallel navigation paths. The camera algorithm achieved 92% accuracy in obstacle detection. The robot is cost-effective due to locally sourced materials. It utilizes solar energy as an alternative power source.

Avantika Sonalikar et al. (2023) [17] designed a solar-powered grass cutter and developed it. It operates using solar energy, reducing fuel costs. The machine is cost-effective and easy to maintain. It is suitable for use in rural areas. The grass cutter occupies less space and is lightweight. Running costs are zero due to solar energy usage. The device can charge its battery while in operation. Performance evaluation was conducted with various grass types.

Michelle Makar et al. (2024) [18] study evaluates various low-power DC-DC converter designs. It identifies a suitable converter for smart glass applications. A 4.8 V to 3.3 V buck converter is recommended. The buck converter shows a minimal output ripple of 0.3%. The research addresses gaps in existing DC-DC converter literature. It provides a comprehensive evaluation of conflicting performance parameters. The study contributes to efficient power solutions for electric vehicles.

3. Problem Statement

On the one hand, the upkeep of wide lawns in the area of houses, shops, malls, airports, etc., is considered to be a resource-demanding and energy-consuming activity as it needs to be performed regularly to maintain a neat and attractive landscape. Besides, protecting the premises when it gets dark is particularly difficult as it requires constant vigilance to notice any would-be trespassers.

The tools and other farming equipment such as freewheeling lawnmowers are not self-steered, or transformed, nor do they possess a holistic system of safeguarding tools making them unfitting for extensive use in areas under threat. This project has put on itself the commitment to perform research in this area and has proposed to make an AI-based lawn mower that would be able to replace the conventional usage of a mower with a more market-friendly option offering additional security to real estate properties as well by integrating cameras and other related home security features.

3. Methodology

This methodology outlines a systematic approach to designing, developing, and integrating technologies for an autonomous lawn mower that incorporates home security features. The process is divided into several stages: research and design, hardware integration, software development, system integration, and testing. Each stage is crucial for ensuring the functionality and efficiency of the final product.

3.1 Problem Definition

Maintaining a clean and smooth lawn remains a difficult and labor-intensive task for most residential and commercial establishments. Traditional lawnmowers are operated purely by hand and can be exhausting and tough, especially for larger or irregularly shaped lawns. Traditional mowers do not have technological elements such as automation, object sensing, or real-time monitoring, thereby making the process more inefficient.

In today's world, securing homes is a big concern for many families. However, there are individual home security systems, but some of those features in a multi-purpose lawn mower will make immense convenience and safety available. There is no such solution in the market today that would provide an all-in-one automated lawn care solution to fulfill the needs of home security as well.

3.2 CAD Model Creation

The detailed and accurate CAD model of the Guardian Lawn will be presented during the design and development of the project. It is critical at this step, before physical fabrication may be undertaken, to visualize the system, break down its components, and thus ensure whole integration. The CAD model is the blueprint of the entire system and, easily pinpoints early design problems in the process.

3.3 Conceptual Design

Begin by sketching the basic structure and layout of the Guardian Lawnmower. This includes the placement of Cutting blades and motors, Wheel assembly and BLDC motor controllers, Grass collection system, including the blower, flexible pipe, and collecting tank, Battery compartments, sensors (LiDAR, GPS), and electronic boards (Raspberry Pi and Jetson Nano).

3.4 Component Modeling

In CAD software, the components are modeled separately. Cutting Blade Assembly: It consists of high-speed rotating blades that are powered by DC motors with an MS plate as support.

- Chassis: The structural base ensures that the chassis will be strong and allows the components to be held safely inside it.
- Grass Collection System: It consists of the blower, flexible pipe, L-bend pipes, and the collecting tank holding 15 Liters.
- Wheel Assembly: This consists of wheels and BLDC motors, along with a mounting system associated with it.
- Specific Mounts for Sensor Elements LiDAR, GPS module, and the security camera. Mounting Battery Sections Two 36V batteries, weighing 18 kg each, are mounted in dedicated compartments.

3.5 Assembly of Components

Using the individual component models, the assembly is created to form a complete virtual prototype of the Guardian Lawnmower. The assembly ensures proper alignment and fitment of all components while maintaining access for maintenance and upgrades.

3.6 Simulation and Analysis

The CAD model undergoes various simulations to test structural integrity, functionality, and efficiency.

- Structural Analysis: Ensures the chassis can withstand loads and vibrations during operation.
- Motion Analysis: Validates the smooth operation of wheels and cutting blades.

3.7 Results Evaluation with Experimental Outcomes

Experimental data was compared with ANSYS results to validate simulation accuracy. Errors were analyzed, and conclusions were drawn. Recommendations for design optimization were provided based on experimental and simulation results.

4. Design

We have used SolidWorks and ANSYS for 3D Modeling, simulation, and analysis. Each software has a specific purpose while developing and designing the lawn mower.

4.1 Design of Frame

The chassis serves as the structural backbone of the mower, supporting all components and providing durability and stability during operation. Its design is optimized to balance strength, weight, and functionality, ensuring that it can withstand operational stresses while maintaining efficiency and maneuverability. The percentage of the chemical composition of the frame is shown in Table 1.

- Material: Stainless steel with Zinc coated (AISI 304)
- Weight: 17.2Kgs
- Cross-Section: Square Tube (30 mm × 30 mm)

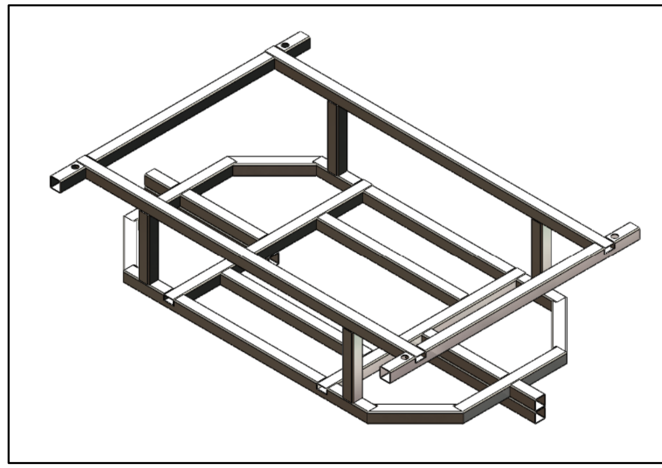

Fig. 1. Isometric View of Frame

Table 1
Percentage of the chemical composition of the frame.

S. No	Material	Percentage
1.	Iron	50–72%
2.	Chromium	16–30%
3.	Nickel	8–10.5%
4.	Molybdenum	2–3%
5.	Carbon	0.03–0.08%

SOLIDWORKS 2023 is used to design to achieve the best optimum geometry as shown in Fig. 1.

- The total length of the frame is 955 mm
- The width of the frame is 700 mm
- The height of the frame is 230 mm

4.2 Design of Suspension Setup

The suspension setup is designed to provide stability, enhance maneuverability, and ensure smooth operation on uneven terrain. The chemical composition of the suspension setup material is as follows Table 2. It absorbs shocks and vibrations, protecting the mower's components and improving the overall performance of the system. The CAD model of the suspension setup is shown in Fig. 2.

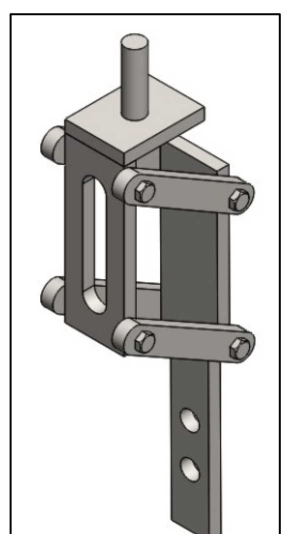

Fig. 2. Isometric View of Suspension Setup

Table 2
Chemical composition of the suspension setup

S. No	Material	Percentage
1.	Tungsten	18–22%
2.	Chromium	4%
3.	Vanadium	1%
4.	Carbon	0.5–1.65%

- Material: High-Speed Steel (HSS)
- Weight: 2.70Kgs

The CAD model of the suspension setup is designed and assembled in SOLIDWORKS 2023.

- The total length of the suspension is
- The width of the suspension is
- The height of the suspension is

4.3 Design of Axle

The axle is a structural component that connects the wheel hub motors and supports the weight of the chassis. Given the use of wheel hub motors, the axle design is simplified but still requires careful consideration to ensure stability, load distribution, and durability during operation.

- Material: High-Speed Steel (HSS)
- Weight: 5.8Kgs (Each)

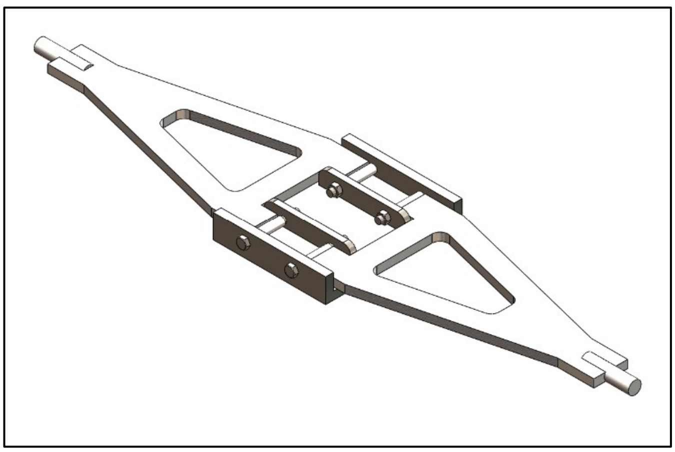

Fig. 3. Isometric View of Axle

The chemical composition of the material is shown in Table 2. The design of the axle is shown in above Fig. 3. The type of axle is A-arm.

- The total length of the axle is 705 mm
- The width of the axle is 180 mm
- The thickness of the axle is 30 mm

4.4 Design of Shock Absorber

The shock absorbers provide effective damping to enhance stability, protect critical components, and improve cutting performance. These absorbers are optimized for the mower's weight and operational environment, ensuring long-term reliability and comfort. The components of the shock absorber were designed and assembled using SOLIDWORKS 2023 as shown in below Fig. 4.

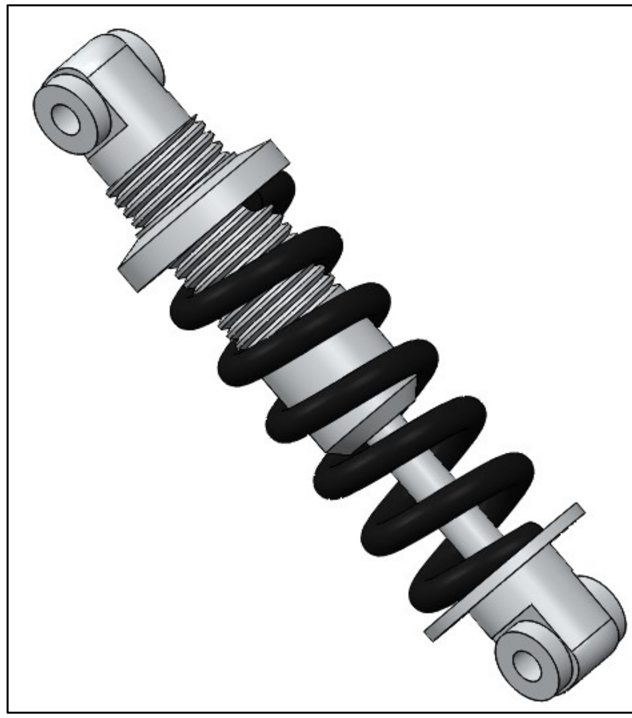

Fig. 4. CAD Model of Shock Absorber

- The diameter of the wire is 7 mm
- The mean coil diameter of the spring is 34 mm

Table 3
Individual component material of the shock absorber

S. No	Component	Material
1.	Top Rod	Gray Cast Iron
2.	Spring	Structural Steel
3.	Base	Gray Cast Iron
4.	Nut	Gray Cast Iron

The material of the individual components of the shock absorber is shown in the above Table 3.

4.5 Design of the Wheel Hub Motor

Wheel hub motors are advanced electric motors integrated directly into the wheel assembly, eliminating the need for external motors, axles, or gears. This design is especially advantageous for applications requiring compactness, efficiency, and direct drive capabilities, such as in the Guardian Lawn project. The CAD model of the wheel hub motor is shown in Fig. 5.

Fig. 5. CAD Model of the Wheel Hub Motor

- Dimensions: 10 × 2.5 Inch
- Material: Aluminum (Wheel Rim)
- Weight: 4.5 Kg (Each)
- Max Speed: 45kmph

4.6 Assembling the components

The assembly process of the Guardian Lawnmower starts with integrating the essential mechanical components of the chassis, suspension setup, wheels, and axle to create a strong and functional foundation for the mower. In below Fig. 6, we can see the assembly of the individual components.

- The total weight of the chassis is 50.8 kg

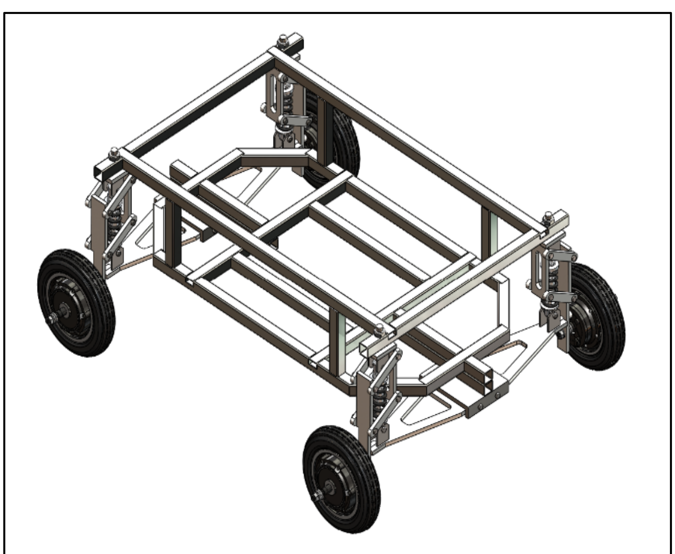

Fig. 6. Chassis of the Lawn Mower

5. Analysis

To evaluate the strength and durability of the mower's chassis, frame, and components under operational loads. Simulates the weight of components like batteries (36 kg combined), motors, and sensors acting on the frame. Identifies stress, strain, and deformation to ensure the chassis can support all components without failure. Tests the frame's ability to withstand sudden impacts, such as hitting a rock or obstacle during operation.

5.1 Analysis of the Frame

To ensure the structural integrity and durability of the frame, a comprehensive analysis of the chassis frame was conducted using SolidWorks. The analysis evaluated the chassis under various loading conditions to identify potential weaknesses and verify its suitability for real-world operations. A CAD model of the designed chassis was calculated by simulating different induced load cases to conduct a finite element analysis of the chassis.

The load cases simulated were:

1. Rear Impact
2. Side Impact
3. Front Impact

The impacts are entirely elastic collisions, and the velocities for the impact test were taken from the International Journal for Mechanical and Industrial Technology.

$F = M \times A$

$A = (V - U) / T$

Factor of Safety (FOS) = Yield Stress / Working Stress

Where,

F - Impact force applied on the vehicle
M - Mass of the vehicle (120kg)
A - Deceleration (negative acceleration)
U - Initial velocity
V - Final velocity
T - Collision time

The maximum speed of the mower is 45 km/hr. So, the impact force at a speed of 40 km/hr for a collision time of 1 sec will be applied.

$A = (45 - 0) / 1$

$= (45 \times 1000) / (1 \times 60 \times 60)$

$= 12.5$ m/s2

$F = 150 \times 12.5 = 1875$ N

We can consider the force as 2000 N for better results.

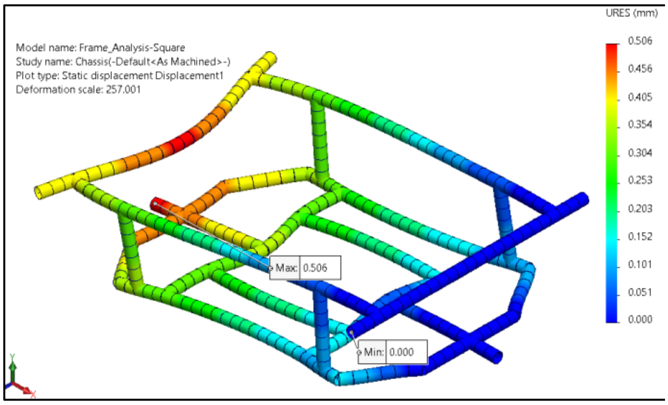

Fig. 7. Deformation due to Rear Impact

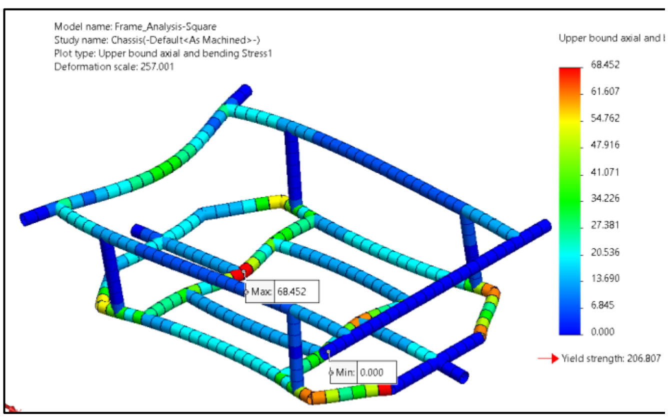

Fig. 8. Stress due to Rear Impact

FOS = 206.807 / 68.452
= 3.02

Deformation:

- Maximum Deformation: 0.506 mm
- Minimum Deformation: 0 mm
- The deformation is within acceptable limits, indicating that the frame maintains its structural integrity under the load.

Stress Distribution:

- Maximum Stress: 68.452 N/mm²
- Minimum Stress: 0 N/mm²
- The maximum stress is well below the material's yield strength, ensuring that no permanent deformation occurs under the applied load.

The chassis frame withstands a rear impact load of 2000 N with minimal deformation and stress values within safe limits. This confirms the frame's robustness and capability to endure rearward collisions, ensuring the mower's operational reliability and safety.

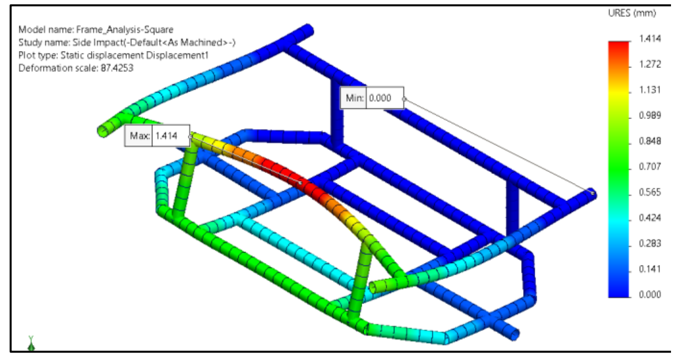

Fig. 9. Deformation due to Side Impact

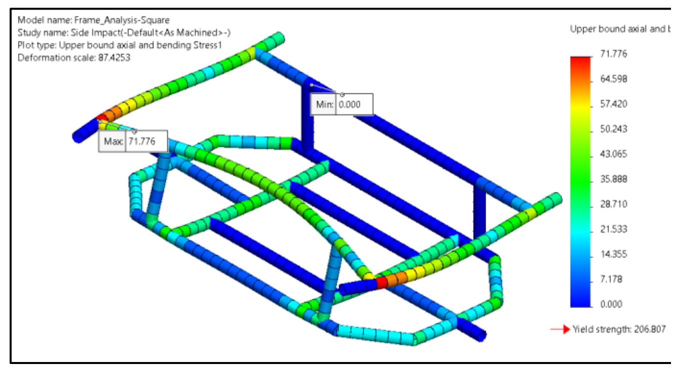

Fig. 10. Stress due to Side Impact

FOS = 206.801 / 71.776 = 2.88

Deformation:

- Maximum Deformation: 1.414 mm
- Minimum Deformation: 0 mm
- The deformation is localized and does not compromise the overall structure, indicating the frame's ability to resist side impacts effectively.

Stress Distribution:

- Maximum Stress: 71.776 N/mm²
- Minimum Stress: 0 N/mm²
- The maximum stress is below the yield strength of the material, ensuring that the frame remains within the elastic deformation range.

The chassis frame demonstrates excellent performance under a side impact load of 2000 N, with deformation and stress values well within the material's safe limits. This confirms the design's lateral strength and resilience, making it suitable for safe operation in real-world conditions.

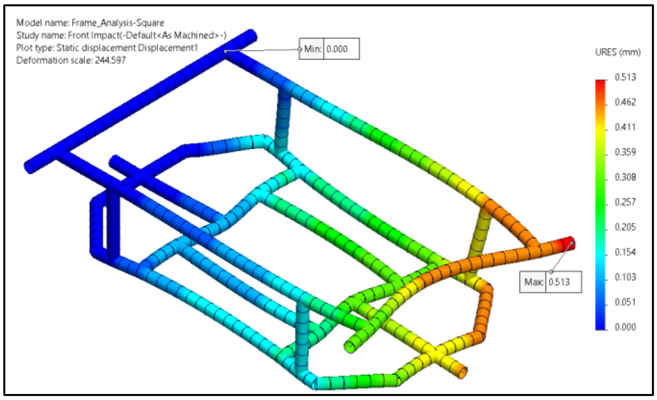

Fig. 11. Deformation due to Front Impact

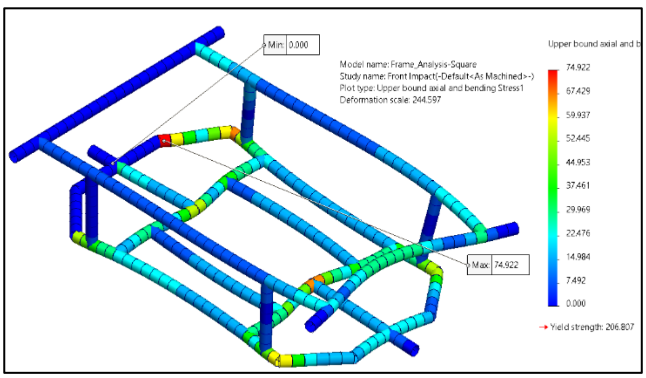

Fig. 12. Stress due to Front Impact

FOS = 206.807 / 74.922 = 2.76

Deformation:

- Maximum Deformation: 0.513 mm
- Minimum Deformation: 0 mm
- The deformation is within acceptable limits, indicating that the frame maintains its structural integrity under the load.

Stress Distribution:

- Maximum Stress: 74.922 N/mm²
- Minimum Stress: 0 N/mm²
- The maximum stress is well below the material's yield strength, ensuring that no permanent deformation occurs under the applied load.

The chassis frame successfully withstood the front impact load of 2000 N with minimal deformation and stress values below the material's yield strength. This confirms that the design is robust and reliable for real-world usage, offering safety and durability during operation.

5.2 Analysis of Wheel Rim

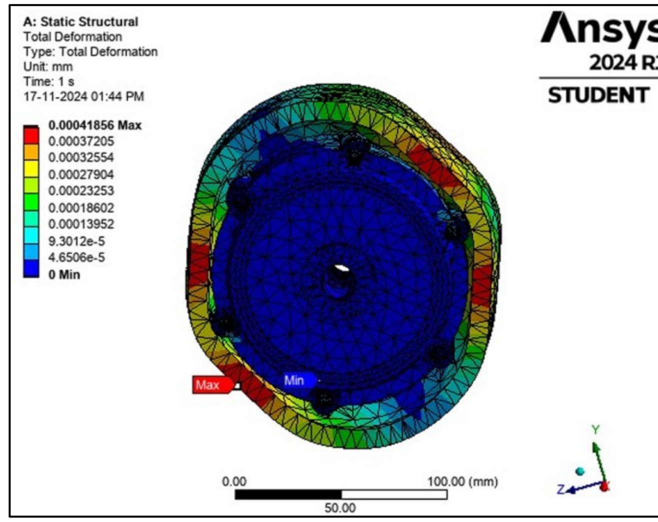

Fig. 13. Deformation of Wheel Rim

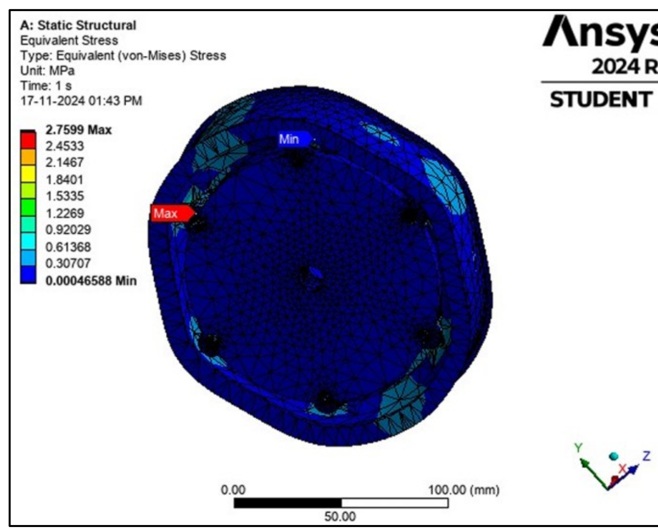

Fig. 14. Stress of the Wheel Rim

The wheel rim analysis is conducted by using ANSYS software to evaluate its structural integrity under operational conditions.

Deformation:

- Maximum Deformation: 0.00041856 mm
- Minimum Deformation: 0 mm
- The wheel rim exhibits very minimal deformation, with a maximum value of 0.00041586 mm. This deformation is well within the acceptable limits for the structural performance of the rim.

Stress Distribution:

- Maximum Stress: 2.7599 N/mm2
- Minimum Stress: 0.00046588 N/mm2
- The maximum stress observed on the wheel rim is within the material's strength limits, suggesting the rim will perform adequately under typical load conditions. The analysis indicates that the rim does not fail due to fatigue or overloading.

5.3 Analysis of Shock Absorbers

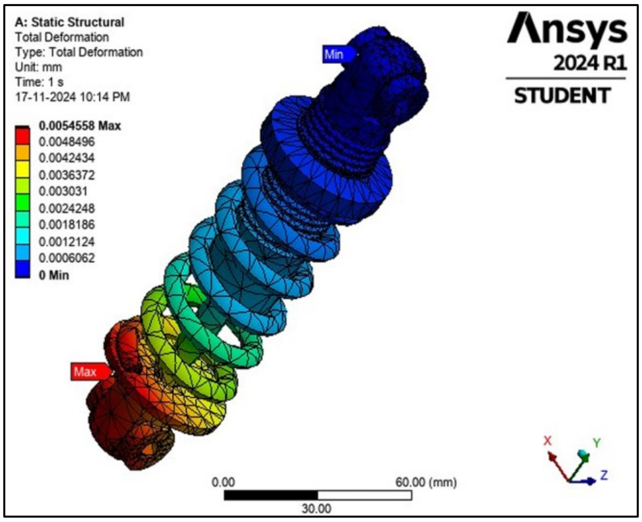

Fig. 15. Deformation of Shock Absorber

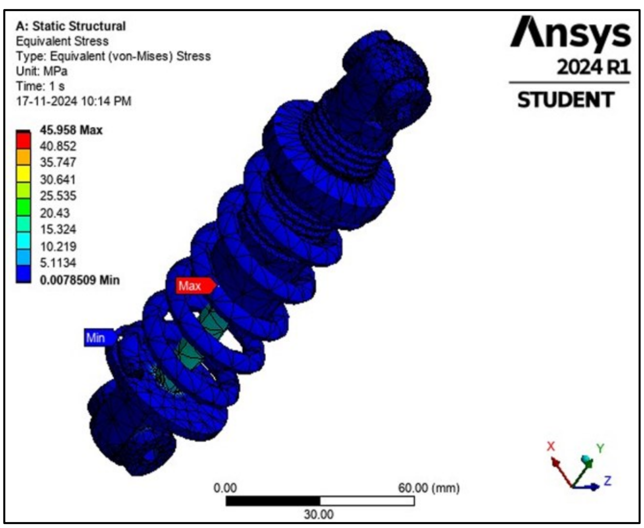

Fig. 16. Stress in Shock Absorber

The shock absorber was analyzed using ANSYS to assess its ability to withstand operational forces and vibrations.
The applied load on the shock absorber is 100 kg.
Deformation:

- Maximum Deformation: 0.0054558 mm
- Minimum Deformation: 0 m
- This indicates that the shock absorber is highly effective at absorbing shocks and vibrations while maintaining structural stability.

Stress Distribution:

- Maximum Stress: 45.958 N/mm^2
- Minimum Stress: 0.0078509 N/mm^2
- The maximum stress observed in the shock absorber is low and within the material's strength limits. The minimum stress values indicate that the structure experiences relatively low stresses.

5.4 Analysis of Axle

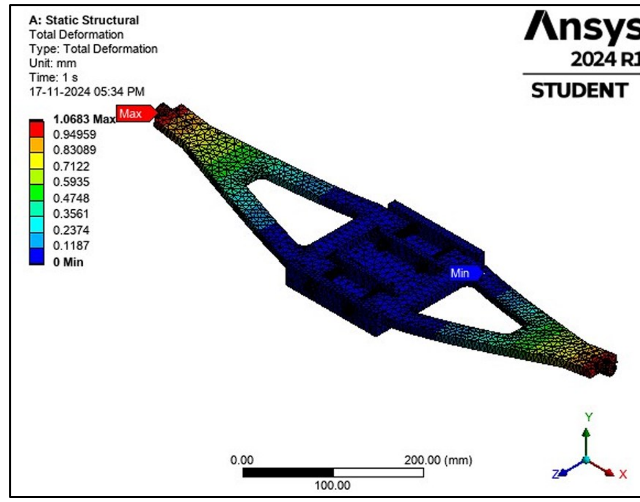

Fig. 17. Deformation of the Axle

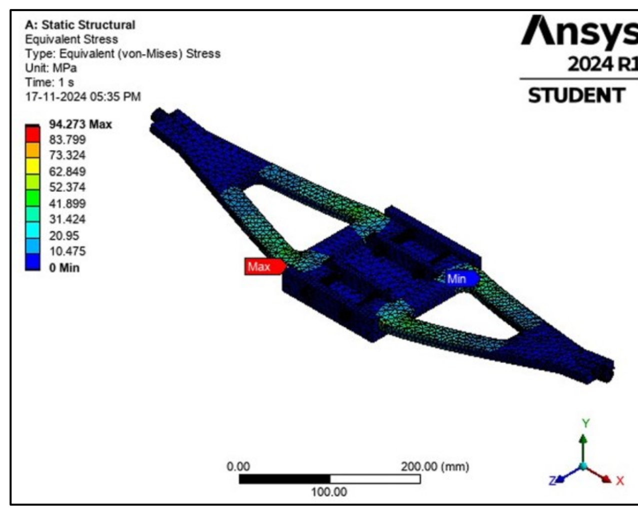

Fig. 18. Stress in the Axle

The deformation analysis showed a maximum deformation of 1.0683 mm, indicating the axle's rigidity. The minimum deformation was recorded as 0 mm, confirming that the design effectively resists excessive bending or warping. These results highlight the axle's ability to maintain stability under significant stress.

Stress analysis was also conducted, with a maximum stress value of 94.273 N/mm^2 and a minimum stress of 0 N/mm^2. The maximum stress is within the yield strength of the high-speed steel (HSS), ensuring that the component can safely handle operational loads without failure.

5.5 Analysis of Suspension Setup

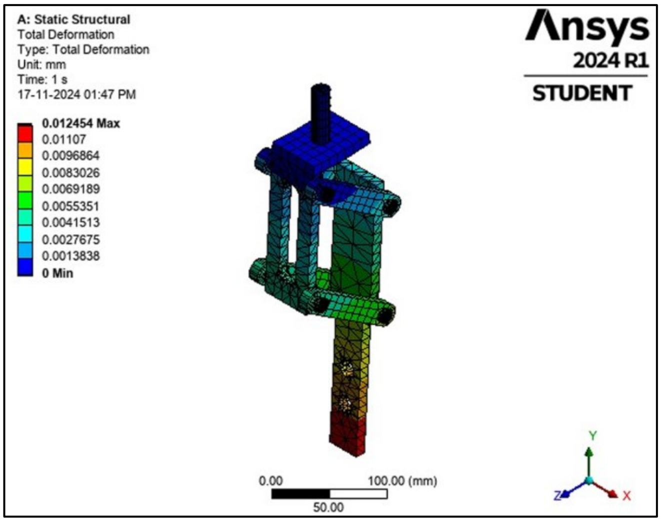

Fig. 19. Deformation of the Suspension Setup

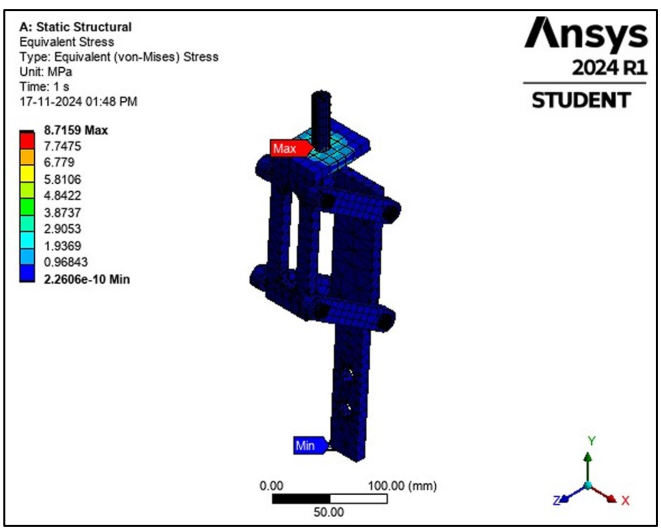

Fig. 20. Stress in the Suspension Setup

The suspension setup underwent a comprehensive structural analysis to ensure its reliability and performance under varying load conditions.

The maximum deformation observed was 0.012454 mm, while the minimum deformation was 0 mm. These values indicate that the suspension setup maintains structural integrity with negligible deformation, ensuring stability during operation.

The maximum stress value was found to be 8.7159 N/mm², while the minimum stress was 2.2606e-10 N/mm². These stress levels are well within the material's yield strength, indicating that the suspension setup can effectively handle operational forces without failure.

The analysis validates the robustness and durability of the suspension setup, making it capable of providing enhanced stability and shock absorption for the lawn mower. This ensures smooth operation even on uneven terrain, reducing vibrations and wear on other components, thereby prolonging the overall lifespan of the mower.

6. Results

In this project Chassis Frame, Axle, Suspension Setup, Shock Absorbers, and Wheel rim are designed which be used in lawns. These are designed as per the required specifications. Therefore, it will give optimum performance. The modeling of the shock absorber is done by using SolidWorks software. Structural analysis is done using SolidWorks and ANSYS software to validate the strength of the design.

6.1 Frame

The Frame made from 30 mm × 30 mm stainless steel square tubes with a zinc coating, were analyzed for structural integrity. The results ensure the chassis is capable of withstanding operational stresses and accidental impacts without compromising its functionality or durability.

Front Impact Analysis:

- Maximum Deformation: 0.513 mm
- Minimum Deformation: 0 mm
- Maximum Stress: 74.922 N/mm²
- Minimum Stress: 0 N/mm²
- Factor of Safety (FOS): 2.76
- The chassis demonstrated excellent resistance to front impact loads, with deformation and stress values well within the safe limits of the material.

Side Impact Analysis:

- Maximum Deformation: 1.414 mm
- Minimum Deformation: 0 mm
- Maximum Stress: 71.776 N/mm²
- Minimum Stress: 0 N/mm²
- Factor of Safety (FOS): 2.88
- The chassis absorbed lateral forces effectively, showing minimal deformation and stress below the yield strength of the material.

Rear Impact Analysis:

- Maximum Deformation: 0.506 mm
- Minimum Deformation: 0 mm
- Maximum Stress: 68.452 N/mm²
- Minimum Stress: 0 N/mm²
- Factor of Safety (FOS): 3.02
- The chassis exhibited robust performance under rear impact loads, with stress and deformation well within permissible ranges.

The stress value for circular pipes is more than for square tubes. The load-carrying capacity of the frame depends on the cross-section. The better chassis design is that which saves material and reduces overall weight, so the frame is designed for higher stresses with smaller dimensions. The stress and deformation for the square tube are within the permission limit.

6.2 Wheel Rim

The wheel rim analysis was conducted to evaluate its structural integrity and performance under operational loads. This ensures the rim can sustain forces and stresses during operation without failure or significant deformation.

Deformation:

- Maximum Deformation: 0.00041856 mm
- Minimum Deformation: 0 mm
- The deformation is negligible, confirming that the rim maintains its shape and functionality under load.

Stress Distribution:

- Maximum Stress: 2.7599 N/mm²
- Minimum Stress: 0.00046588 N/mm²
- The stress values are well below the material's yield strength, ensuring that the rim will not fail under operational conditions.

These results demonstrate that the wheel rim design is robust, lightweight, and suitable for the demanding conditions of the lawn mower's operation.

6.3 Axle

The axle analysis was conducted to assess its ability to withstand operational and impact loads during the Guardian Lawn mower's usage. This ensures the axle is structurally robust and capable of transmitting forces effectively without failure or significant deformation.

Deformation:

- Maximum Deformation: 1.0683 mm
- Minimum Deformation: 0 mm
- The deformation is minimal and within acceptable limits, indicating structural stability under load.

Stress Distribution:
Maximum Stress: 94.273 N/mm²
Minimum Stress: 0 N/mm²
The stress values are below the yield strength of the material, ensuring no permanent deformation or failure under the applied load.

6.4 Shock Absorber

Deformation:

- Maximum Deformation: 0.0054558 mm
- Minimum Deformation: 0 mm
- Minimal deformation ensures that the shock absorber retains its shape and function during operation.

Stress Distribution:

- Maximum Stress: 45.958 N/mm²
- Minimum Stress: 0.0078509 N/mm²
- The stress values are significantly below the material's yield strength, ensuring durability and long service life.

These results confirm that the shock absorber design contributes significantly to the mower's stability, operational efficiency, and comfort.

6.5 Suspension Setup

The suspension setup underwent a comprehensive structural analysis to ensure its reliability and performance under varying load conditions.

Deformation:

- Maximum Deformation: 0.012454mm
- Minimum Deformation: 0 mm
- Minimal deformation ensures that the suspension setup retains its shape and function during operation.

Stress Distribution:

- Maximum Stress: 8.7159 N/mm²
- Minimum Stress: $2.2606e^{-10}$ N/mm²
- The stress values are significantly below the material's yield strength, ensuring durability and long service life.

The analysis validates the robustness and durability of the suspension setup, making it capable of providing enhanced stability and shock absorption for the lawn mower.

CONCLUSION

A review of the parts of the Guardian Lawn Mower, namely its chassis, wheel rims, axle, and shock absorbers, establishes the strength and reliability of the design. The chassis showed minimal deformation and stress both when hit by impact loads from the front, side, and back, confirming that it can successfully withstand operational and accidental forces. Strength and corrosion resistance from the zinc coating makes the stainless steel even more tenable. The wheels were similarly healthy, showing minimal deformation and stress values, justifying their ability to work well in surviving the dynamic loads experienced during movement.

The axle and shock absorbers add more strength to the structural framework of the mower. The axle showed outstanding resistance to strain and deformation, meaning it would be reliable for many years of operation in dynamic conditions. Shock absorbers absorb vibrations and their impact forces, thus providing stability and comfort in uneven terrain. The overall analysis confirms that the Guardian lawn mower is intended for heavy usage conditions ensuring safety, durability, and work efficiency for users.

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