Materials Research Proceedings 31 (2023) 666-673 https://doi.org/10.21741/9781644902592-68

Modeling and simulation of modular agricultural robot flexible production systems

Mohammed Aldossary[1,a *], Yousuf Alsuliman[1,b], Abdul Aziz Afzal [1,c], Stephen Limbos[1,d] and Megdi Eltayeb[1,e]

[1]Department of Mechanical Engineering, Prince Mohammad Bin Fahd University

[*a]mdossary2920@hotmail.com, [*b]Yousuf.alsuliman@gmail.com, [*c]aafzal@pmu.edu.sa, [d]slimbos@pmu.edu.sa, [e]meltayeb@pmu.edu.sa

Keywords: Modeling, Simulation, Agricultural, Robot, Finite Element Analysis

Abstract. This paper outlines the stages in the development of an integrated modular system for agricultural robots through distinct concepts, designs, and analyses of the outcomes. The integrated modular system must be developed and produced to the highest standards for all probable situations and obstacles in diverse agricultural activities in order to improve an efficient autonomous agricultural robotic modular system. The agricultural robot is designed in accordance with design principles to produce a final product. Design concepts were made, and then a virtual prototype was created in SolidWorks with the necessary dimensions to simulate the dynamic simulation and working space, and the prototype. The finite element analysis of the integrated modular system for agricultural robots test based on the stress, strain, deformation, and mechanical analysis simulations carried out in SolidWorks, uses the virtual model as an input to verify the impact and mechanical properties. The primary objective of this study is to create a high-quality integrated modular system useful for developing supplementary agriculture tools and operations. In this study, modeling and analysis of an integrated modular system for agricultural robots are reported. The modular system is modeled in 3D using the software SolidWorks, and its static structural analysis is performed using SolidWorks. To determine the deformation, stresses, strains, and forces that the loads have on the structures, a static-structural analysis is carried out. Under static structural analysis, the following results for a modular system made were obtained: equivalent von-mises stress, total deformation, and equivalent von-mises strain.

Introduction

Modular agricultural robots are becoming increasingly popular in the agricultural industry. These robots are designed to help farmers increase their efficiency and productivity while reducing costs. They can be used for a variety of tasks such as planting, harvesting, and weeding. With the help of modeling, design, and simulation, these robots can be customized to meet the needs of specific crops or farms. The use of these agricultural robots can enable farmers to maximize their yields while minimizing their labor costs. Moreover, a robot is considered a mechatronic system consisting of several electronically controlled mechanisms. Based on the application of the robot, specific design parameters have to be taken place. The primary objective is to determine the effectiveness of the proposed project. It provides an estimate of the resources obtained to achieve the project requirement and its constraints for completion. Designing a farming robot includes the ability to perform agriculture tasks in a farming field, where the robotics concept aims to improve the processes involved in the agriculture cycle. The chassis of an agricultural robot is a crucial-component in its design and mechanics. It needs to be able to withstand the load or stress encountered during operation while performing its tasks. This requires careful consideration of the structural design, geometry and material used in the construction of the chassis.

Materials Research Proceedings 31 (2023) 666-673 https://doi.org/10.21741/9781644902592-68

Methodology and simulation

The robot's chassis is the structure that supports and contains the primary mechanisms and all of the instrumentation and electronics that power it. Also, the chassis must accommodate all the stresses caused by the applied loads by the robot operations. The structure manages the different forces experienced by the robot, either internally or by conveying them to the ground. The frame must handle the driving and steering motors within the wheels. Furthermore, the robot chassis is a foundation that connects the upper mechanism to the motors and conveying forces applied. These parameters can be controlled by several aspects while designing a chassis for a farming robot, such as structure, size, material, modeling, and analysis that simulate the performance.

Structure. Chassis structure designs were obtained based on comparing commercial and prototype agricultural robots, aiming to reduce total mass while increasing the volume for the required components. However, one of the most critical factors that must be considered when designing the chassis is the overall structure capable of distributing the load applied statically and dynamically while operating. Also, other essential factors that are generally needed to be considered while optimizing the chassis are the overall weight, economic aspects, performance and sustainable chassis design, in which extra features may be installed on the chassis without affecting stability or load distribution. Moreover, from comparing different chassis structures such as square, rectangular, circular, Y-shape and truss-shaped, an implemented H-shaped structure has been observed that is less consuming material, lighter weight, sufficient stress distribution and sustainable modular design. In addition, the mechanical construction of the agricultural robot was established by utilizing the virtual prototyping approach, which is a phase in the product development process. Furthermore, it includes utilizing CAD and CAE tools to evaluate a design before committing to producing actual artifacts.

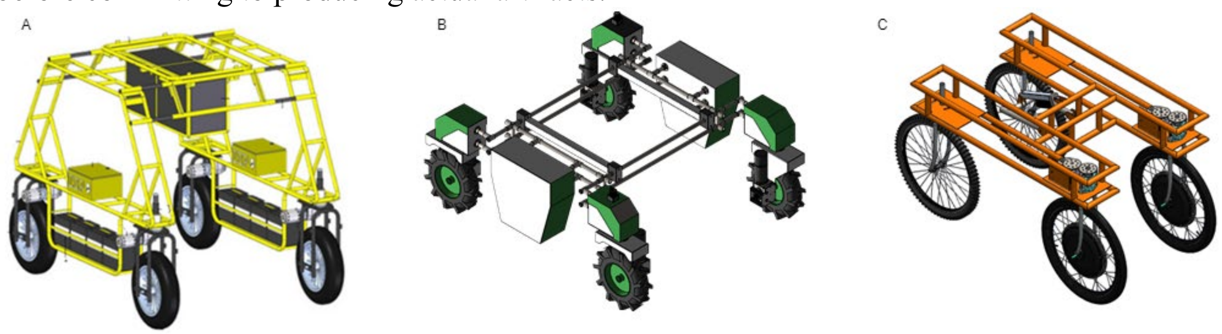

Figure 1: (A) Truss-shaped chassis, (B) Square shaped chassis, (C) Optimized H-shaped chassis

The first design in Fig. 1(A), acquire strong structure and a large space where modular equipment design is possible. In the other hand, it has a lot of tubes, heavy and too highly spaced form soil which requires excess of material to carry the agricultural implements. The second design shown in Fig. 1(B), is the most common mobile robot structure, which provide critical spacing for tools, but less in term of strength and rigidity since the design has to many joints such as binary, ternary, and quaternary joints. The chassis optimized for the project as illustrated in Fig. (C), achieves the objectives of the design, such as handling the load applied, less material requirement, and being sustainable in terms of integrating futuristic features to the design. Also, the robot's operating speed is modest, so there is no need to construct a suspension system. Overall, the design process is done by creating computer-generated geometrical shapes, combining them into an assembly, and testing different mechanical motions, fit and function. Additionally, the assembly or individual parts could be optimized in CAD software to simulate the different stresses the product may encounter in the real world. However, the mechanical structure was designed symmetrically between the right and left sides, allowing the homogenous weight distribution and simplifying the project's development. Moreover, designing a chassis requires consideration of the beam structure. It is important to ensure that the beams are strong enough to support the weight of the vehicle and its contents, while at the same time not being overly bulky and heavy. The profile of the beam also needs to be taken into account, as this will dictate the amount of space available for other components within the chassis. Furthermore, the profile needs to be well-suited for any welding and fastening that may encounter during manufacturing processes.

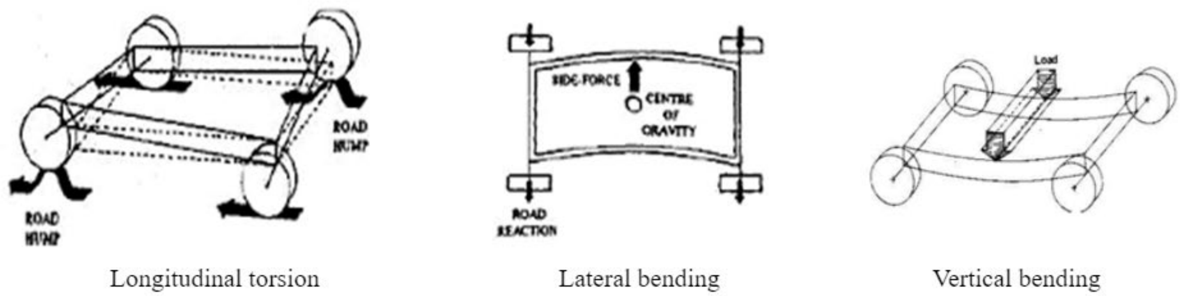

Figure 2: Chassis operation conditions

Structural beams are an essential element of construction, providing strength and support for the various structures that is built. This is because a beam profile determines its strength and rigidity, which can be useful when designing a structure with complex requirements. A wide range of beam profiles can be used depending on the project's needs, such as square beams, rectangular beams, and circular beams. Furthermore, when choosing the structural beam profile, the overall dimensions must be defined to make sure that the constructed chassis is rigid and doesn’t deform within unaccepted range during operation, such as those illustrated in Fig. 2.

Figure 3: Structural beam profiles

The structural profile shown in Fig. 3, demonstrates the chosen cylindrical beam profile. Cylindrical beams are becoming increasingly popular for the construction of vehicle chassis due to their strength and durability. However, these beams offer superior torsional stiffness, which allows them to withstand twisting forces without distortion. Additionally, they provide superior lateral stiffness which keeps them from buckling under pressure. Cylindrical beams are also lightweight, making them ideal for reducing overall vehicle mass.

Design. The dimensions are chosen after considering the numerous issues that might arise from sizes. The constructed chassis was implemented based on field operation requirements, weight distribution, and stress concentration. The chassis size is critical to the stress distribution process and determines the robot's kinematics. This robot's chassis has an overall dimension of 1.5x0.9x0.85 m, as illustrated in Fig. 4.

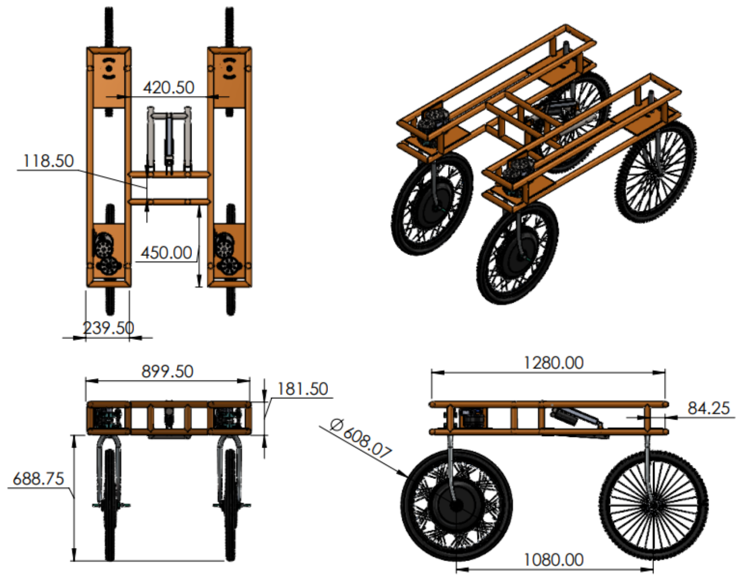

Figure 4: Modular agricultural robot dimension

Likewise, the structure must function in crops with varying spacing of up to 90 cm in height. The chassis structure implemented as a result of design optimization was H-shaped, which is light and flexible and decreases weight while enhancing efficiency when compared to commercial agricultural vehicles. Furthermore, because of the height of the robot, the distance between axles must allow the vehicle to overcome slopes, which are common in crop fields. The short wheelbase helps the vehicle's agility but makes it more difficult to handle. However, because our goal is to create a flexible vehicle, the wheelbase is selected to provide only sufficient space for tools while still allowing for maximum mobility.

Materials. When deciding the material of constructing the chassis and its component, it required to sort all the parameters that need to addressed, mechanical properties, stress concentration, manufacturability, weight and cost. Those parameters can be controlled by choosing the suitable material, by utilizing three different materials that have been observed within the study such as those typically used in vehicle chassis. The selection criteria were mainly subjected to mechanical properties of the material behavior within application characteristics that meets the design requirements, Table 1 illustrate the three materials studied.

Table 1: Material properties comparison

Parameters	ASTM A36 Steel	AISI 1020 Steel	AISI 4310 Steel
Yield Strength [MPa]	250	351	460
Ultimate Strength [MPa]	400.0	420.5	731.0
Modulus of Elasticity [GPa]	200	200	205
Modulus of Rigidity, [GPa]	79.3	72.0	80.0
Poisson's Ratio	0.260	0.290	0.285
Density [kg/m^3]	7850	7900	7850

From the table above, an observation based on material characteristics has been specified to compare between those material, such as yield strength, modulus of rigidity, Poisson's ratio and material density. ASTM A36 is a common structural steel grade used in construction and fabrication applications. It is an economical, general-purpose steel with good strength, formability, and weldability characteristics. However, it is particularly well-suited for applications where strength and toughness are needed in combination. It can be used in many areas such as buildings, bridges, highways, and other structures, as well as in industrial maintenance, agricultural applications, transportation equipment, and general fabrication. In addition, it achieves the requirement of being ductile and difficult to deform under various stress that might encounter during operation. These conditions are controlled by specific mechanical properties targeted such as yield strength, modulus of elasticity and modulus of rigidity. Ductile materials are essential for robot chassis building, they provide a highly durable and lightweight structure that robots need to operate effectively. Also, its easily manipulated to fit into any shape and size desired, allowing for customization of the chassis design to suit different needs. Additionally, ductile materials are extremely resilient and can withstand harsh exterior environments, protecting the sensitive internal components from damage. Moreover, the robot chassis is best constructed from a material that is both strong and ductile, such as those that can be stretched and hammered out into desired shapes without breaking. These materials like aluminum, steel and titanium, are perfect for constructing a robot's chassis as they can be shaped to meet any desired form. Furthermore, they can withstand greater forces and pressures than other materials, making them more durable and reliable in the long run. Additionally, ductile materials boast a high modulus of elasticity, which gives them the ability to flex and bend when forces are applied, without becoming permanently deformed. This property makes them an ideal fit for constructing a chassis, as it can absorb impacts and shocks from the environment while safely protecting its internal components. In conjunction with its high modulus of elasticity, the ductile material used to construct a robot's chassis also has a significant modulus of rigidity. This means that, while the material is still pliable, it will not deform irreversibly when subjected to pressure. High modulus of rigidity allows the chassis to remain rigid and stable in its structure, further protecting its internal components from damage. This makes the material selected perfect to be utilized, as it can remain rigid enough to protect its components, while still being resilient enough to withstand impacts and shocks from operational conditions.

Results and discussions. The material properties which were utilized in finite elements analyses were obtained from SolidWorks as shown in Table 1 for the ASTM-A36 steel. In order to simplify the model, elements that have no structural function as electronic controls, batteries, motors and steering system have been removed from analysis. The removed items have been replaced by resulting forces.

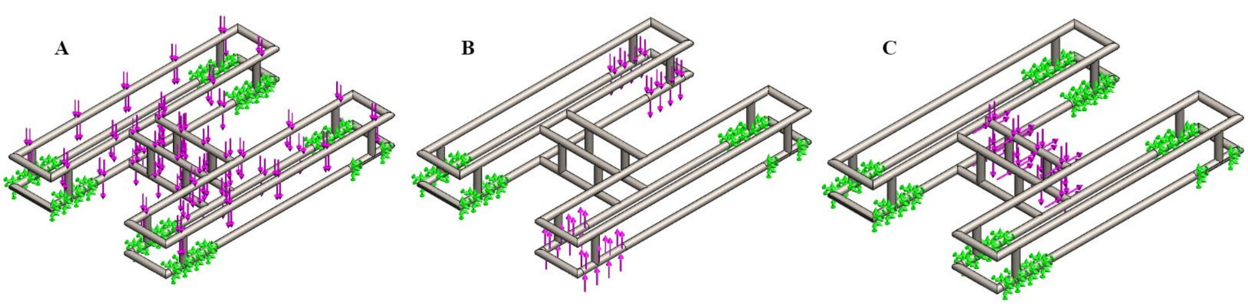

Figure 5: Loads applied on the structure: (A) Vertical bending, (B) Longitudinal torsion, (C) Combined bending

The details of the structure with the forces applied are presented in Fig. 5. Simulation has been performed considering the structure under condition of variable strain in three cases: (A) Vertical bending due to maximum weight of 80 kg; (B) Longitudinal torsion due to crossing obstacles with 20 kg applied at each corner; and (C) Combined bending due to farming implements with maximum mass of 30 kg.

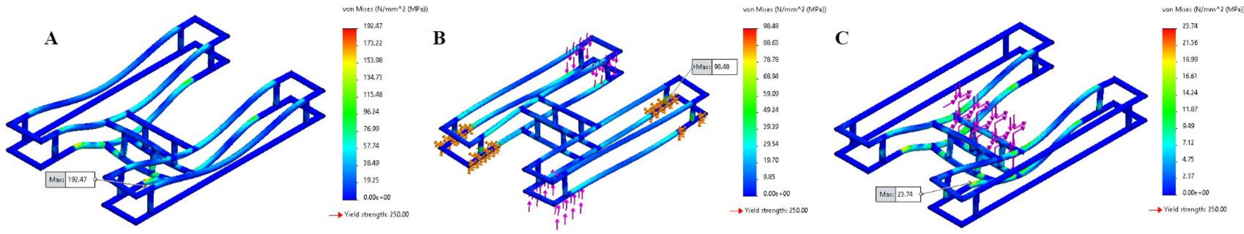

Figure 6: Maximum Stress: (A) Vertical bending, (B) Longitudinal torsion, (C) Combined bending

Fig. 6, shows the results of the stress analysis. It is clear to see that the majority of the deformation happened in the lower section of the chassis, but without affecting the set's performance. In terms of tension, there was some stress deposition at the joint of the bottom and inner side frames, but not enough to cause permanent deformation.

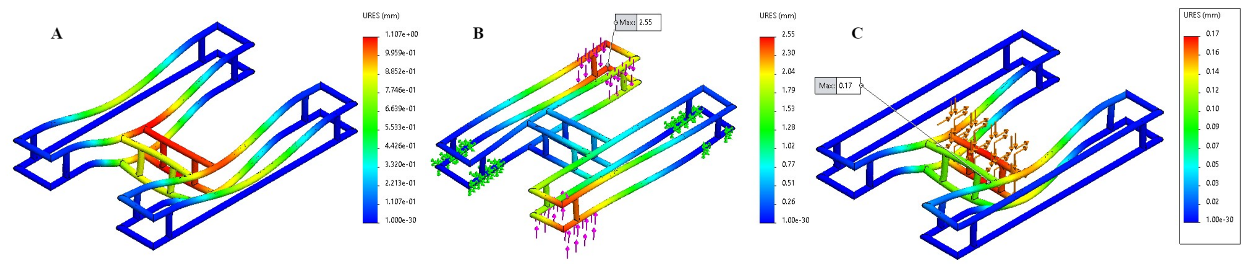

Figure 7: Maximum Deformation: (A) Vertical bending, (B) Longitudinal torsion, (C) Combined bending

Fig. 7, shows the deformations obtained from the analysis for each of the cases investigated. The maximum deformation is found at the rear corner of the chassis, and it decreases as it shifts toward the middle cross members of the chassis. This characteristic is expected to occur, which is due to longitudinal torsion and the distance between the wheel modules and the center connection between the side frames.

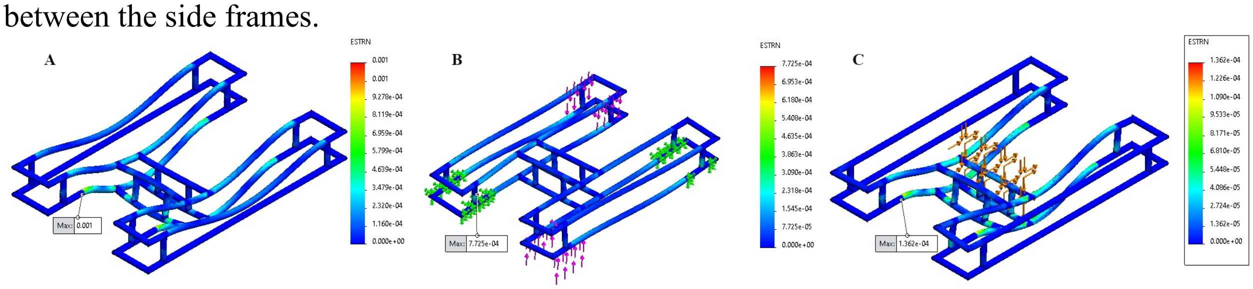

Figure 8: Maximum Strain: (A) Vertical bending, (B) Longitudinal torsion, (C) Combined bending

Fig. 8, illustrate the results of maximum strain that would occur during operational conditions. As a result, most of strain in the structure would initiate from the fixed supports, due to the ductility of the material selected.

Table 2: Simulation results

Design Parameters	Case [a]	Case [b]	Case [c]
Maximum stress [MPa]	192.47	98.48	23.74
Maximum deformation [mm]	1.1	2.55	0.17
Maximum strain [mm/mm]	0.001	0.0008	0.00014
Factor of safety	1.30	2.54	10.53
Average stress [MPa]	104.9		
Average factor of safety	2.38		

Table 2, shows parameters obtained from the simulation results. In maximum stress detected, the analysis shows the design would obtain 1.3 factor of safety, which is almost critical for a ductile material. Maximum deformation characteristics in a robot vehicle chassis play an important role in its overall performance. Through the simulation, maximum deformation observed is 2.55 mm, acceptable based on the prototype geometrical scale. Such characteristics are evaluated through dynamic tests and are important for evaluating the overall robustness of a design.

Conclusion

This paper presents the modelling and simulation of an integrated modular system for agricultural robot operations in the agricultural industry. This study presents modeling and analysis of the integrated modular system for agricultural robots. The modular system is modeled in the finite element analysis and the computer-aided design using the software SolidWorks, and its static structural analysis is performed using SolidWorks under different loading conditions. The integrated modular system is not expected to break under various loading situations, according to the analysis's findings, which were assessed using the deformation, stresses, and strain failure analysis criterion. The integrated modular system will be able to carry out the tasks during the agricultural processes with accuracy and precision.

References

[1] Diary Ali, R. (2020). Design and Development of a Chassis Concept for an Autonomous Airport Shuttle (Dissertation). Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-280558

[2] Tabile, R. A., Godoy, E. P., Pereira, R. R. D., Tangerino, G. T., Porto, A. J. V., & Inamasu, R. Y. (2010). Design of the mechatronic architecture of an agricultural mobile robot. IFAC Proceedings Volumes, 43(18), 717–724. https://doi.org/10.3182/20100913-3-us-2015.00102

[3] Vijayaragavan, E., Bhat, S., Patel, A., & Rana, D. (2018). Design and analysis of a mobile robot for storage and retrieval system. IOP Conference Series: Materials Science and Engineering, 402, 012205. https://doi.org/10.1088/1757-899x/402/1/012205

[4] P. (2021). Structural & dynamic analysis and simulation of mobile transportation robot. International Journal of 3D Printing Technologies and Digital Industry. https://doi.org/10.46519/ij3dptdi.949803

[5] Agarwal, A., & Mthembu, L. (2022). Structural Analysis and Optimization of Heavy Vehicle Chassis Using Aluminium P100/6061 Al and Al GA 7-230 MMC. Processes, 10(2), 320. https://doi.org/10.3390/pr10020320

[6] Rothmund, M., & Institut Für Landtechnik, B. U. U. (2006). Automation Technology for Off-road Equipment 2006: Proceedings of the 1 - 2 September International Conference, Bonn, Germany. Landtechnik Weihenstephan.

[7] Michaud, S., Richter, L., Thüer, T., Gibbesch, A., Huelsing, T., Schmitz, N., Weiss, S. T., Krebs, A., Patel, N. D., Joudrier, L., Siegwart, R., Schäfer, B., & Ellery, A. (2006). Rover Chassis Evaluation and Design Optimisation using the RCET. International Conference on Robotics and Automation. https://doi.org/10.3929/ethz-a-010043426