https://doi.org/10.22306/atec.v11i4.301 Received: 18 Aug. 2025; Final revised: 11 Sep. 2025; Accepted: 20 Nov. 2025

Design and technological development of robotic platforms for agricultural plant care

Tran Thanh Tung
Faculty of Engineering Mechanics and Automation, VNU University of Engineering and Technology, 144 Xuan Thuy Street, Ha Noi, 10000, Vietnam, tranthanhtung@vnu.edu.vn
Nguyen Thi Anh
Faculty of Mechanical Engineering, Thuyloi University, 175 Tay Son, Ha Noi, 10000, Vietnam, nguyenthianh200197@tlu.edu.vn
Nguyen Xuan Quynh
School of Mechanical Engineering, Ha Noi University of Science and Technology, 1 Dai Co Viet, Ha Noi, 10000, Vietnam, quynh.nguyenxuan@hust.edu.vn
Tran Vu Minh
School of Mechanical Engineering, Ha Noi University of Science and Technology, 1 Dai Co Viet, Ha Noi, 10000, Vietnam, minh.tranvu@hust.edu.vn (corresponding author)

Keywords: agricultural robotic, plant care, manufactured, prototype.
Abstract: In the context of modern agricultural transformation, the integration of robotic systems into plant care is emerging as a vital solution to address challenges such as labour shortages, increased production demands, and the need for sustainable farming practices. This research focuses on the mechanical design and fabrication of a compact, modular robotic platform specifically tailored for agricultural plant care applications. The robot is designed to operate in greenhouses or open fields and is equipped with a four-wheel differential drive system, a chain transmission mechanism, and a load-distributing aluminium top plate to support essential components such as a water tank. Finite Element Analysis (FEA) was conducted to validate the structural reliability of the chassis and loadbearing elements, showing low stress and strain well below material limits, thereby ensuring operational stability and safety. A prototype was manufactured using accessible materials and methods, demonstrating the feasibility of the proposed design in terms of assembly, mobility, and structural integrity. This study contributes a mechanically robust and scalable foundation for future integration with sensors and control systems, advancing the development of smart, automated agricultural robotics.

1 Introduction

In the context of agriculture's rapid transformation toward modernization and automation, the integration of robotic technology into plant care processes has become increasingly critical [1-3]. Tasks such as pesticide spraying, weed removal, environmental monitoring, and growth assessment are labour intensive and time consuming when performed manually. Automating these stages not only addresses the growing shortage of agricultural labour but also improves operational efficiency, consistency, and sustainability in modern farming practices [4-10].

To meet these emerging demands, this research is dedicated to the mechanical design and development of a robotic system specialized for agricultural plant care. The objective is to design and fabricate a compact, modular robot capable of operating in medium to large scale environments such as greenhouses and open field farms. Emphasis is placed on a simulation-oriented prototype that enables practical validation and conceptual demonstration of the mechanical subsystems involved.

The research focuses exclusively on mechanical design, covering aspects such as chassis layout for rough terrain mobility, articulated arms for multitask functionality, and tool mounting systems for interchangeable plant care implements. Consideration is given to factors such as structural stability, ease of component integration, environmental durability, and manufacturability. The robot's frame, drive system, and end effector mechanisms are developed with a view to flexibility, enabling the robot to adapt to different crop geometries and terrain conditions.

Beyond the practical design objective, the project also serves an educational purpose providing hands on experience in mechanical design, structural analysis, and mechatronic system integration. Through this effort, the study contributes not only a working prototype but also a framework for future research in agricultural robotics focusing on mechanical design innovation.

2 Related work

Plant care robots represent a significant advancement in the application of robotics within the domain of modern agriculture. These robots are engineered to autonomously perform essential tasks such as irrigation, fertilization, environmental monitoring, and crop health assessment by measuring parameters like humidity, temperature, and soil moisture. The integration of robotic systems into plant care processes not only reduces the dependency on manual labor but also enhances the precision, consistency, and efficiency of agricultural operations.

In the context of ongoing challenges in the agricultural sector including labor shortages, rising production demands, and the need for sustainable practices plant care robots emerge as a promising technological solution. They play a pivotal role in advancing the transition toward smart, sustainable, and environmentally responsible farming. By automating repetitive and data intensive tasks, these robots contribute to increased productivity, optimized resource usage, and improved crop management, aligning with the broader goals of intelligent agricultural systems.For example, Zhang, Maoqing, et al [11] proposes two novel strategies a sliding window method and a placeholder strategy to optimize watering robot path planning and address challenges such as dimensionality and environmental variability, validated through a genetic algorithm with neighbor exchange. Amin Ghobadpour [12] discusses the emerging trends and future prospects of green energy based off road electric vehicles and autonomous robots in agriculture, highlighting their potential to address challenges such as labor shortages, energy demands, and environmental sustainability through electrification, renewable energy, and integration with advanced digital technologies. Ditzler, Lenora, and Clemens Driessen [13] investigates how robots can support agroecological farming specifically within the context of pixel cropping in the Netherlands arguing that automation in diversified, ecology based systems requires rethinking robotic design to align with agroecological values through inclusive, iterative, and hybrid approaches rather than fully replacing human labor. D Xie et.al [14] reviews the core technologies of agricultural robots operating in unstructured environments focusing on actuators, control systems, perception tools, and end effectors and highlights how their integration is driving the transition toward data driven, standardized, and unmanned smart agriculture. Fábio P. Terra et.al [15] proposes a low cost, modular robotic sprayer system using computer vision and individual nozzle control to optimize pesticide application in row crops, aiming to enhance food safety, reduce environmental impact, and provide an affordable automation solution for small and medium sized farms. Yu, Jiangfan, et al [16] develops an automatic maize seeding machine integrating sand filling, seed placement, watering, and covering, and proposes an image based evaluation method to optimize spray angle settings concluding that a 55° spray angle offers the best balance of watering efficiency, minimal seed disturbance, and uniform moisture distribution, as quantified by a novel Spray Angle Performance Index (SAPI). Fu, Qiqi, et al [17] designs an improved greenhouse self-propelled precision sprayer with a Multiple Height and Level (MHL) rack and advanced sensing technologies, demonstrating that it offers greater spray uniformity and operational stability compared to traditional systems, while also highlighting its precision and cost-saving potential through comparative analysis. Luo Y et.al [18] proposes a suspended rail automatic variable distance spray system for solar greenhouses, which uses laser sensing and real time control to optimize nozzle positioning for vertically cultivated crops demonstrating a 16.65% increase in pesticide adherence and a 29.58% reduction in pesticide use compared to fixed-distance spraying, thereby enhancing precision, efficiency, and environmental sustainability. Yao, Zhixin et.al [19] reviews and compares existing research on autonomous navigation and path planning technologies for agricultural machinery, categorizing key methods such as GNSS, machine vision, and LiDAR, detailing 22 algorithms across four planning approaches, and highlighting unresolved challenges and future research directions to enhance obstacle avoidance and path optimization. Wang, Yue, et al [20] develops an intelligent wall mortar spraying robot featuring a retractable structure for extended working range, laser based parallel adjustment, and LiDAR driven area recognition, demonstrating its ability to autonomously align with walls, avoid non spray zones, and effectively perform automated spraying with high accuracy and efficiency. Given the diversity of robotic applications and the advancements in precision agricultural technologies reviewed above, it is evident that plant care robotics holds substantial potential to address critical challenges in modern farming. Therefore, this research was conducted to contribute a specialized mechanical design solution tailored to the needs of plant care automation, aiming to enhance operational efficiency, adaptability, and sustainability in smart agriculture systems.

3 Mechanical design architecture

3.1 Overall structural design

The proposed plant care robot features a compact, modular frame constructed primarily from aluminium extrusion profiles, providing both structural integrity and design flexibility. The overall dimensions of the robot are 560 mm (length) × 410 mm (width) × 220 mm (height), making it suitable for navigating narrow crop rows or greenhouse aisles. The platform accommodates a 5-10 kg water tank, centrally positioned for balanced load distribution.

A four-wheel configuration is used to ensure mobility and ground stability, with robust rubberized wheels designed for semi-structured terrains. The drivetrain utilizes two chain-driven systems connected to stepper motors for independent left right wheel control, enabling differential steering. The chains are tensioned and guided by sprockets mounted on both motor shafts and wheel axles to ensure synchronized movement and torque transmission (Figure 1).

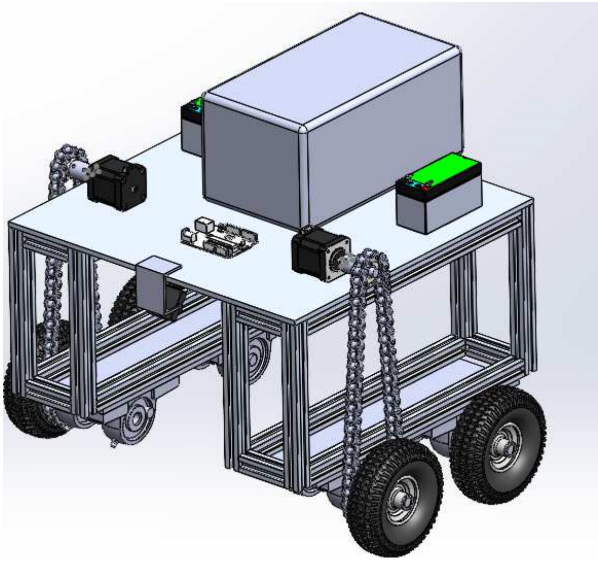

Figure 1 Mechanical design overview of the plant care robot platform

The gap between the two supporting leg frames is 200 mm, allowing the system to straddle over narrow crops or rows, minimizing interference with the plants during operation. The top surface supports electronics and power systems (not shown), while the bottom region remains accessible for future integration of spraying arms, sensing modules, or robotic manipulators.

3.2 Chassis and frame design

The chassis of the plant care robot is designed with a focus on modularity, lightweight construction, and adaptability to semi-structured agricultural environments. The entire frame is fabricated using 20×20 mm 6063-T5 aluminium profiles, chosen for their excellent balance of strength to weight ratio, corrosion resistance, and ease of machining and assembly. The use of extruded aluminium allows for future component integration and structural adjustments without requiring welding or cutting, enhancing maintainability.

The robot's overall frame structure consists of three main segments:

Central support platform (footrest): measuring 105 mm (height) × 400 mm (length) × 200 mm (width), serves as the mechanical core for mounting electronic components and the water tank (5-10 kg capacity).

Side legs: symmetrically positioned with a 200 mm gap between them to straddle plant rows without disturbing crops.

Small connecting frame: sized 200 mm × 240 mm, reinforces lateral stability and provides a mounting base for drive systems or sensor modules.

The top frame layout, as shown in Figure 2 includes transverse beams to support both mechanical loads and modular attachments such as spraying arms or vision systems. The frame's open design allows air circulation around electronic components and provides access for maintenance.

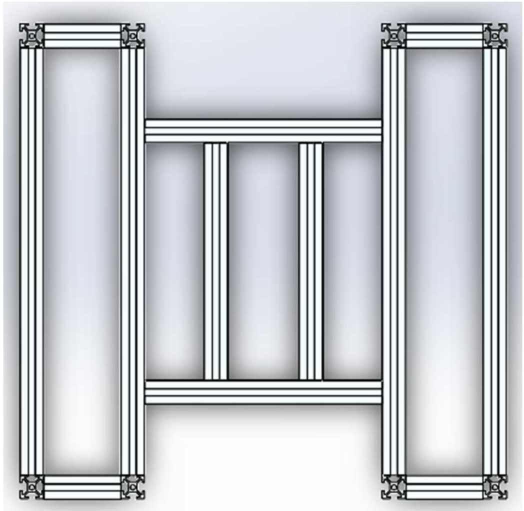

Figure 2 Chassis and frame design

This compact aluminium-based frame design ensures the robot remains both structurally stable and lightweight, meeting the mobility and load bearing requirements of medium to large scale plant care applications in greenhouses or open fields.

To evaluate the mechanical reliability of the top platform under operational loads, a finite element analysis (FEA) was conducted. The simulation assesses the von Mises stress distribution across a 6 mm thick 6061-T6 aluminium plate mounted on the frame and subjected to a uniform load of approximately 70 N, representing the weight of components such as the water tank and electronics.

As shown in Figure 3, the von Mises stress values across the structure range from 83.7 Pa to 57.9 kPa, with stress concentrations observed near the plate corners—likely due to localized boundary conditions or fixed constraints. Importantly, the maximum stress value ($\approx 5.8 \times 10^4$ N/m²) is significantly lower than the material's yield strength of 275 MPa (2.75×10^8 N/m²) for 6061-T6 aluminium. This indicates a very high safety factor, confirming that the platform will remain within the elastic deformation range and not experience plastic deformation or failure under normal operating conditions.

The results validate the design decision to use 6061-T6 for the top plate and confirm the adequacy of the supporting 6063-T5 aluminium frame. The system is structurally sound for the expected loading, ensuring durability and stability during field operation.

Acta Tecnologia - International Scientific Journal about Technologies
Volume: 11 2025 Issue: 4 Pages: 193-199 ISSN 2453-675X

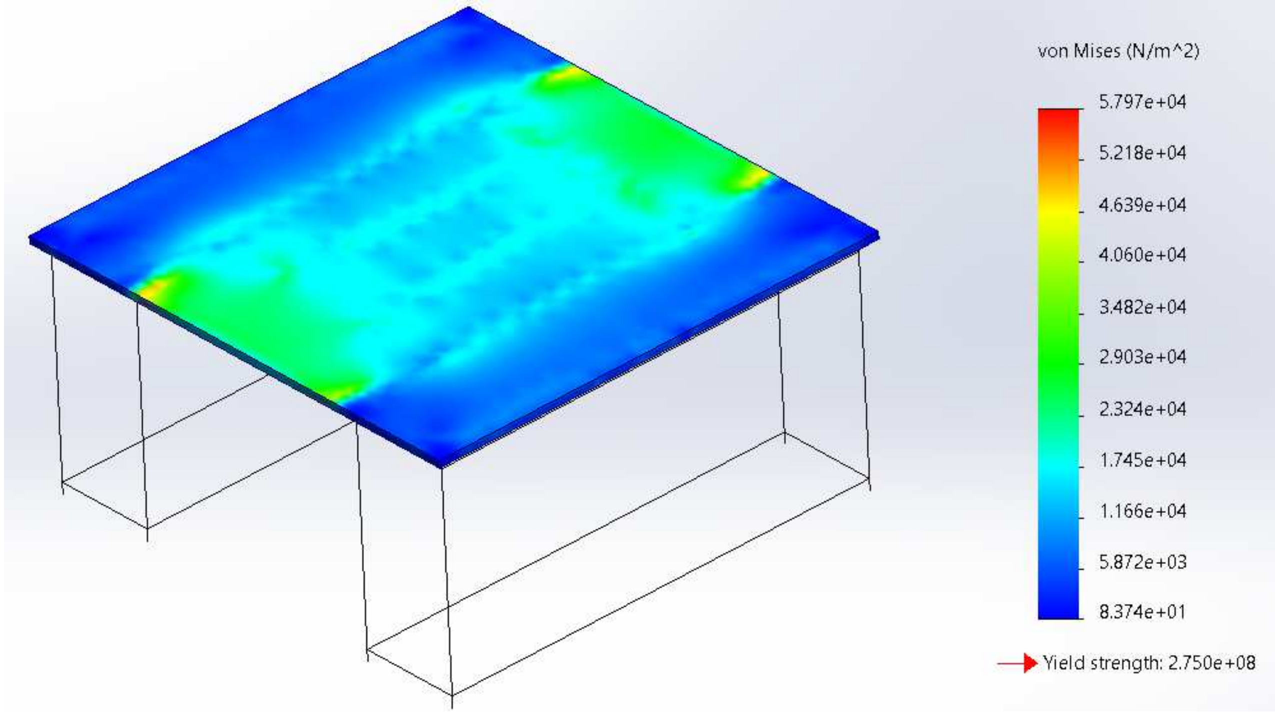

Figure 3 The von Mises stress distribution from frame

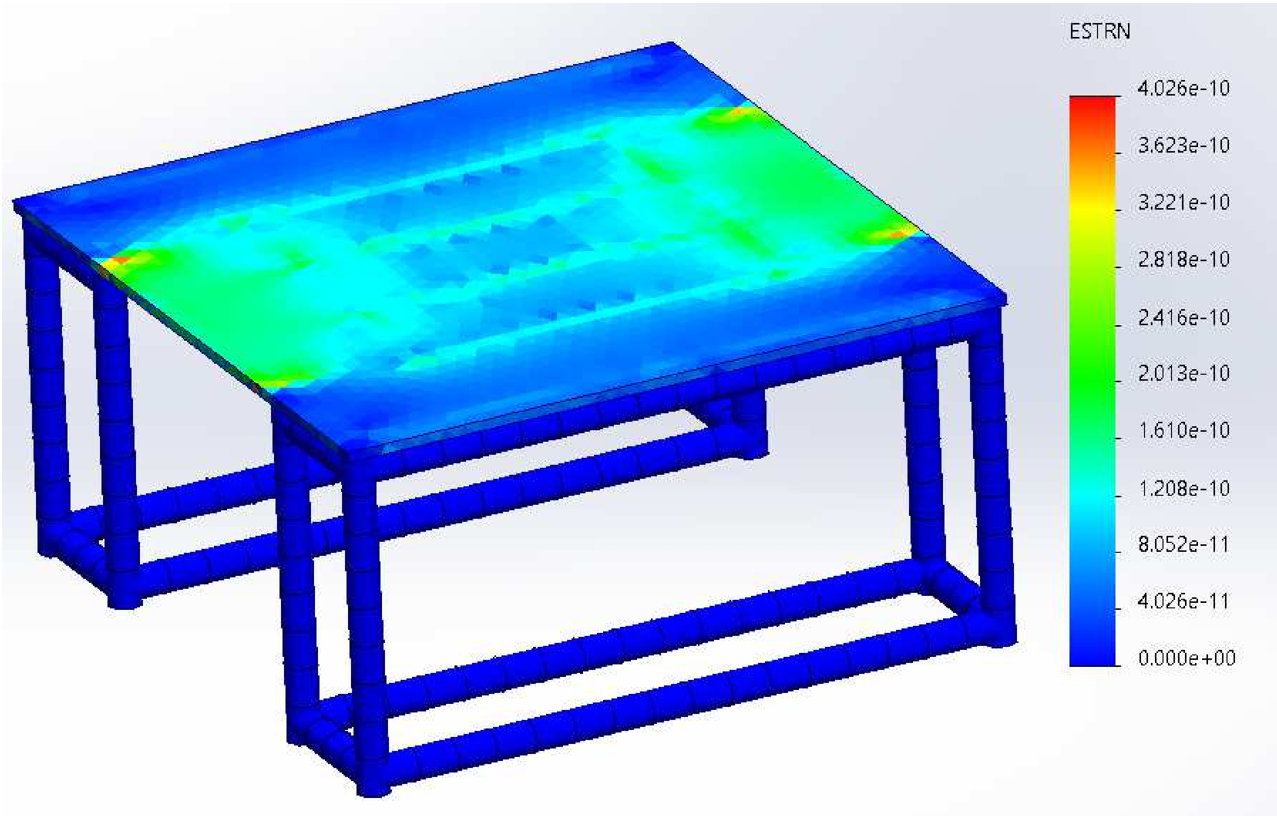

Figure 4 The equivalent strain (ESTRN) across the frame

To complete the structural validation, a strain analysis was performed under the same loading and boundary conditions used in the previous stress and displacement simulations. The plot in Figure 4 illustrates the distribution of equivalent strain (ESTRN) across the frame and top aluminium plate.

The results indicate extremely low strain values throughout the structure, with peak strain reaching approximately 4.03×10^{-10}. These values are orders of magnitude below typical strain thresholds for structural deformation in 6061-T6 and 6063-T5 aluminium, confirming that the entire chassis and load-bearing plate remain well within the elastic deformation range.

Strain concentrations are mildly visible at the corners of the plate corresponding with locations of stress accumulation, but these are still negligible in magnitude. The rest of the frame exhibits near-zero strain, which aligns with expectations given the lightweight loading scenario (~70 N) and the material stiffness.

These results further validate that the current mechanical design ensures durability, elastic recovery, and structural safety, with no risk of plastic deformation or fatigue under nominal operational loads.

4 Results and discussion

All in-text citations should be listed in the reference list at the end of your document (Figure 2, Figure 3).

Following the completion of the mechanical design and structural validation, a full-scale prototype of the plant care robot was fabricated and assembled, as shown in Figure 5. The development and assembly of the agricultural plant care robot prototype were carried out in strict accordance with the proposed mechanical design specifications, resulting in a structurally accurate and functionally stable system. The chassis was constructed using 20×20 mm 6063-T5 aluminium extrusion profiles, chosen for their excellent mechanical properties, corrosion resistance, and ease of assembly. These lightweight yet durable components formed the skeleton of the robot, offering high structural integrity and modularity. To address concentrated loading and enhance structural performance, a 6 mm thick 6061-T6 aluminium plate was mounted on the top surface of the frame. This plate acted as a load distribution platform, accommodating an estimated operational payload of 70 N, which includes the water tank (up to 10 kg), drive components, and potential sensor modules. Under static loading conditions, the prototype maintained its shape with no visible signs of deformation, deflection, or instability, demonstrating its robustness and suitability for semi-structured agricultural environments such as narrow crop rows or greenhouse aisles.

To further evaluate mechanical performance, finite element analysis (FEA) was conducted to simulate structural behaviour under loading. The von Mises stress analysis revealed that the maximum stress was approximately 57.9 kPa, located near the corner constraints of the aluminium plate. This value is significantly lower than the yield strength of 275 MPa for 6061-T6 aluminium, providing a substantial margin of safety and confirming the structure's ability to operate under normal agricultural conditions without risk of yielding or failure. Strain analysis (ESTRN) further indicated minimal deformation, with peak strain values around 4.03×10^{-10}, which is orders of magnitude below the elastic threshold, thus confirming that the materials remain well within the elastic range throughout operation. These results validate the choice of materials and confirm the adequacy of the load-bearing structure in terms of stiffness, strength, and long-term reliability.

The displacement simulation showed a smooth distribution of deflection, with the maximum occurring at unsupported plate edges. Although some exaggerated values appeared due to mesh density or improperly constrained boundary conditions in the simulation software, the physical prototype showed no noticeable warping, tilting, or deflection during preliminary loading and mobility tests. Observations from manual push tests confirmed the frame's resistance to torsion and bending, reinforcing confidence in its use on uneven terrain with minor vibrational loads.

The mobility system, consisting of four wheels and a chain-driven differential mechanism, also underwent design verification and theoretical performance evaluation. The drivetrain was built using 04C chain and sprocket components, with a gear ratio of 2:5 achieved through a 12-tooth sprocket on the motor and a 30-tooth sprocket on the drive axle. This configuration effectively reduces wheel rotation speed while increasing torque by 2.5 times, making it suitable for agricultural use where high torque and low speed are prioritized over rapid motion. Calculations show that, with the selected motors (JGB37 series), the output torque at the wheel can reach over 2 Nm per motor, generating a combined tractive force of approximately 63.7 N, which is sufficient to move a 20 kg load under typical rolling resistance conditions. While the motors used in the current prototype were simulation units, the drivetrain demonstrated consistent alignment and tension, with the chain remaining engaged and responsive under test movement. Minor irregularities such as chain lag or stalling were observed, primarily due to insufficient motor power in the prototype, which will be addressed in future iterations by integrating higher power geared motors.

In summary, the prototype exhibited excellent compliance with mechanical and structural expectations. The modular design enables easy disassembly and upgradeability, the fabricated frame is lightweight and mechanically sound, and the system is well-suited for integration with additional components such as sensors, actuators, and control electronics. The FEA results, supported by physical observations, indicate that the current mechanical structure can confidently support further development toward full automation. This validation provides a solid foundation for advancing the project to the next phase, including control integration, sensor-based perception, and autonomous plant care functionalities.

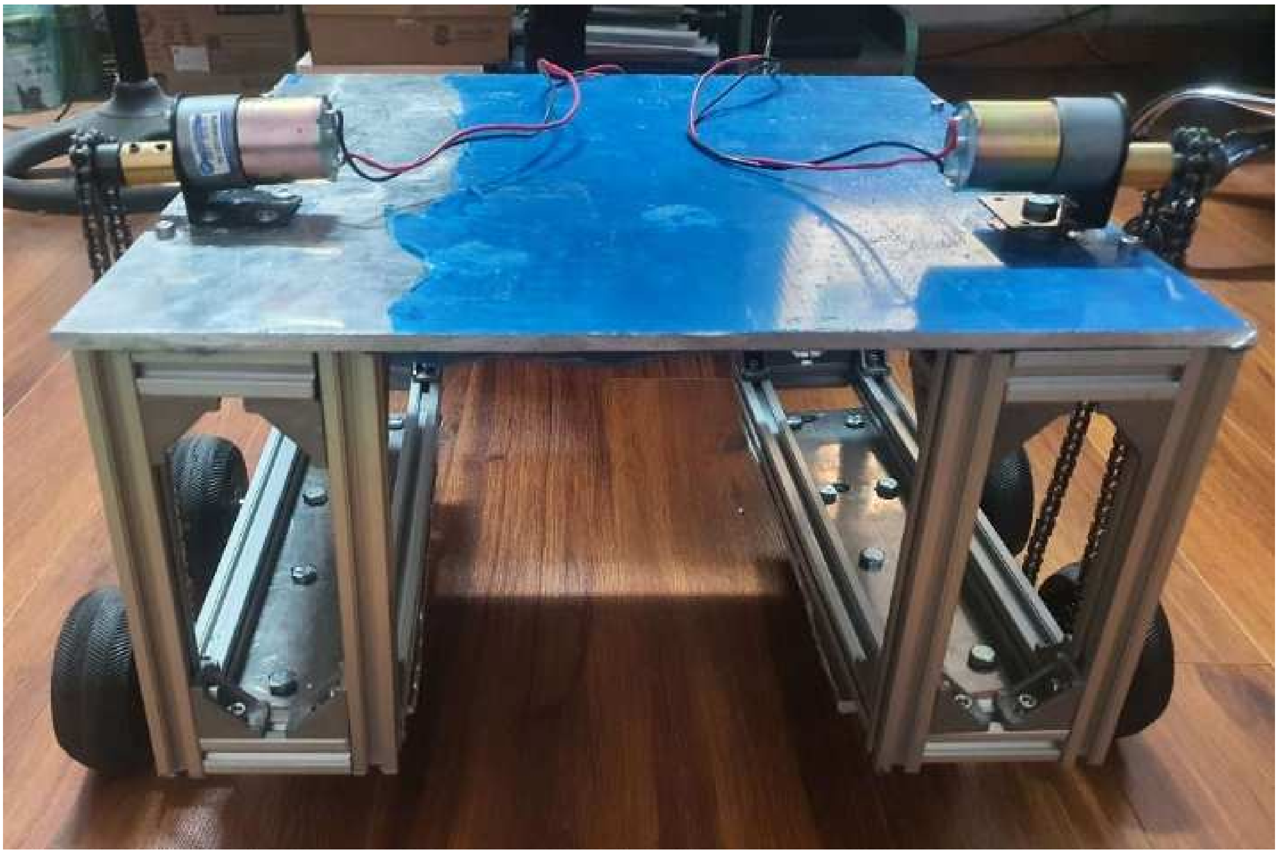

Figure 5 A full-scale prototype of the plant care robot

5 Conclusions

This study successfully designed, analysed, and fabricated a mechanical prototype of a robotic platform intended for plant care applications in agriculture. By focusing exclusively on mechanical architecture, the project established a robust and modular frame constructed from 6063-T5 aluminium profiles, combined with a 6 mm thick 6061-T6 aluminium plate for load distribution. Key mechanical subsystems, including a differential drive system with chain transmission and a compact wheelbase, were developed to support operation in structured environments such as greenhouses and narrow crop rows. Finite Element Analysis (FEA) confirmed the structural integrity of the design under operational loads, with stress and strain levels significantly below the yield limits of the materials used. The physical prototype was assembled using accessible manufacturing techniques and materials, validating the design's manufacturability, rigidity, and ease of assembly.

Building upon the successful development of the mechanical prototype, future work will focus on transforming the platform into a fully autonomous and intelligent agricultural robot. This includes integrating sensor systems such as soil moisture sensors, ultrasonic or LiDAR modules, and environmental monitors to enable real-time interaction with crop conditions. A control system based on microcontrollers (e.g., Arduino or Raspberry Pi) will be implemented to manage motor control, process sensor data, and execute plant care routines. In addition, the robot's navigation capabilities will be enhanced through the application of GPS, vision-based tracking, or predefined path planning to ensure precise movement within crop rows or greenhouse environments. Modular end-effectors for watering, spraying, and crop monitoring will also be designed for quick attachment and task flexibility. Finally, efforts will be made to improve energy efficiency and sustainability, including exploring the use of solar panels for outdoor operation. These advancements aim to transform the current mechanical platform into a smart, adaptable, and scalable solution for modern agriculture.

References

[1] AMPATZIDIS, Y., DE BELLIS, L., LUVISI, A.: iPathology: Robotic Applications and Management of Plants and Plant Diseases, *Sustainability*, Vol. 9, No. 6, 1010, pp. 1-14, 2017. https://doi.org/10.3390/su9061010

[2] ATEFI, A., GE, Y., PITLA, S., SCHNABLE, J.: Robotic Technologies for High-Throughput Plant Phenotyping: Contemporary Reviews and Future Perspectives, *Frontiers in Plant Science*, Vol. 12, No. June, 611940, pp. 1-18, 2021. https://doi.org/10.3389/fpls.2021.611940

[3] CHENG, C., FU, J., SU, H., REN, L.: Recent Advancements in Agriculture Robots: Benefits and

Challenges, *Machines*, Vol. 11, No. 1, 48, pp. 1-24, 2023. https://doi.org/10.3390/machines11010048

[4] HAFEEZ, A., HUSAIN, M.A., SINGH, S.P., CHAUHAN, A., KHAN, M.T., KUMAR, N., CHAUHAN, A., SONI, S.K.: Implementation of drone technology for farm monitoring & pesticide spraying: A review, *Information processing in Agriculture*, Vol. 10, No. 2, pp. 192-203, 2023. https://doi.org/10.1016/j.inpa.2022.02.002

[5] HEJAZIPOOR, H., MASSAH, J., SORYANI, M., VAKILIAN, K.A., CHEGINI, G.: An intelligent spraying robot based on plant bulk volume, *Computers and Electronics in Agriculture*, Vol. 180, No. January, 105859, 2021. https://doi.org/10.1016/j.compag.2020.105859

[6] NGUYEN, V.-T., TUNG, T.T.: Development of a prototype of weeding robot, *Engineering Research Express*, Vol. 6, No. 1, 015411, pp. 1-14, 2024. https://doi.org/10.1088/2631-8695/ad3403

[7] LI, Y., GUO, Z., SHUANG, F., ZHANG, M., LI, X.: Key technologies of machine vision for weeding robots: A review and benchmark, *Computers and Electronics in Agriculture*, Vol. 196, No. May, 106880, 2022. https://doi.org/10.1016/j.compag.2022.106880

[8] OLIVEIRA, L.F.P., MOREIRA, A.P., SILVA, M.F.: Advances in Forest Robotics: A State-of-the-Art Survey, *Robotics*, Vol. 10, No. 2, 53, pp. 1-20, 2021. https://doi.org/10.3390/robotics10020053

[9] HALDER, S., AFSARI, K.: Robots in Inspection and Monitoring of Buildings and Infrastructure: A Systematic Review, *Applied Sciences*, Vol. 13, No. 4, 2304, pp. 1-37, 2023. https://doi.org/10.3390/app13042304

[10] JIN, Y., LIU, J., XU, Z., YUAN, S., LI, P., WANG, J.: Development status and trend of agricultural robot technology, *International Journal of Agricultural and Biological Engineering*, Vol. 14, No. 4, pp. 1-19, 2021. https://doi.org/10.25165/j.ijabe.20211404.6821

[11] ZHANG, M., GUO, W., WANG, L., LI, D., HU, B., WU, Q.: Modeling and optimization of watering robot optimal path for ornamental plant care, *Computers & Industrial Engineering*, Vol. 157, No. July, 107263, 2021. https://doi.org/10.1016/j.cie.2021.107263

[12] GHOBADPOUR, A., MONSALVE, G., CARDENAS, A., MOUSAZADEH, H.: Off-Road Electric Vehicles and Autonomous Robots in Agricultural Sector: Trends, Challenges, and Opportunities, *Vehicles*, Vol. 4, No. 3, pp. 843-864, 2022. https://doi.org/10.3390/vehicles4030047

[13] DITZLER, L., DRIESSEN, C.: Automating Agroecology: How to Design a Farming Robot Without a Monocultural Mindset?, *Journal of Agricultural and Environmental Ethics*, Vol. 35, 2, pp. 1-31, 2022. https://doi.org/10.1007/s10806-021-09876-x

[14] XIE, D., CHEN, L., LIU, L., CHEN, L., WANG, H.: Actuators and Sensors for Application in Agricultural Robots: A Review, *Machines* Vol. 10, No. 10, 913, pp. 1-31, 2022. https://doi.org/10.3390/machines10100913

[15] TERRA, F.P., NASCIMENTO, G.H.D., DUARTE, G.A., DREWS-JR, P.L.: Autonomous Agricultural Sprayer using Machine Vision and Nozzle Control, *Journal of Intelligent & Robotic Systems*, Vol. 102, 38, pp. 1-18, 2021. https://doi.org/10.1007/s10846-021-01361-x

[16] YU, J., ZHANG, Z., LIU, X., CHEN, K., LI, Y., IGATHINATHANE, C., WANG, X., ZHANG, M., LI, H., HA, T.: Automatic maize seeding machine watering spray angle determination by using a novel index, *Computers and Electronics in Agriculture*, Vol. 224, No. September, 109234, 2024. https://doi.org/10.1016/j.compag.2024.109234

[17] FU, Q., LI, X., ZHANG, G., MA, Y.: Improved greenhouse self-propelled precision spraying machine—multiple height and level (MHL) control, *Computers and Electronics in Agriculture*, Vol. 201, No. October, 107265, 2022. https://doi.org/10.1016/j.compag.2022.107265

[18] LUO, Y., HUANG, D., JIANG, P., XIANG, S., LIU, J., XU, M., SHI, Y.: Design and Experimental Testing of an Overhead Rail Automatic Variable-Distance Targeted Spray System for Solar Greenhouses, *Agriculture*, Vol. 13, No. 9, 1853, pp. 1-17, 2023. https://doi.org/10.3390/agriculture13091853

[19] YAO, Z., ZHAO, C., ZHANG, T.: Agricultural machinery automatic navigation technology, *iScience*, Vol. 27, No. 2, 108714, pp. 1-20, 2024. https://doi.org/10.1016/j.isci.2023.108714

[20] WANG, Y., XIE, L., WANG, H., ZENG, W., DING, Y., HU, T., HU, J.: Intelligent spraying robot for building walls with mobility and perception, *Automation in Construction*, Vol. 139, No. July, 104270, 2022. https://doi.org/10.1016/j.autcon.2022.104270

Review process
Single-blind peer review process.