

Design and Implementation of a Robotized Laser Module for Weed Control

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Abstract: This paper presents the design of a low-cost, modular system mounted on a mobile platform for weed control using laser technology. This proposal seeks to find an effective and sustainable solution for selective weed management in agricultural settings, avoiding harmful methods such as herbicides. The methodology for this work was based on the application of divergent-convergent thinking stages. Additionally, studies were conducted on potential movement systems, and in line with the system's needs, a Core XY movement was selected. Standard elements and custom designs were adapted to the previous structure. Similarly, an analysis of potential casing designs was carried out, and through a convergent process, a design suitable for its function was selected. The results obtained in this work, such as the estimated movement system accuracy of less than 0.2mm and the simulated treatment time of 3.62 seconds, in an estimated area of 0,25 m², demonstrate the feasibility of creating an effective, small-sized, and low-cost weed control system for users, providing the necessary precision to avoid damage to surrounding crops.

1 INTRODUCTION

Despite the long history of humanity and its coexistence in society, it is in recent centuries that the world has experienced significant population growth, due to various factors, among them globalization (Bonanno, 1994; Byerlee et al., 2009). This exponential increase in the number of people clashes with the capacity of traditional agricultural methods to sustain the growing demand for food, leading to shortages and rising prices; in addition to other effects resulting from unregulated agricultural activities, such as desertification (Danfeng et al., 2006; Portnov and Safriel, 2004). This is why new production methods are needed, as well as a review of existing ones to improve their efficiency. Among these alternative approaches, agroecology stands out for promoting agricultural systems that are both productive and ecologically balanced, by integrating local knowledge with ecological principles. It emphasizes biodiversity, soil health, and community involvement, promoting food systems that work in harmony with nature.

In the quest to meet this growing demand, precision agriculture has emerged as a more efficient alternative. This is an agricultural practice that combines different technologies to optimize the management of crops and agricultural resources (Zhang and Kovacs, 2012). It is based on the collection and analysis of detailed data about the area of operation, such as soil condition or weather conditions. With this data, the aim is to achieve more targeted and efficient management of agricultural practices, maximizing crop yields while reducing the resources required and the resulting environmental impact.

In recent decades, this has led to the integration of robotics with traditional agricultural processes in order to improve efficiency and increase production volume (Emmi et al., 2023). Numerous developments have focused on different stages of production, many of them on the final stages of harvesting and sorting the end product. An example of this type of robot is presented by the company FarmWise (FarmWise Labs, 2024), capable of mechanically and selectively remove detected weeds while simultaneously collecting information about them and the terrain. Other key developments within this field are Carbon Robotics (Carbon Robotics, 2025), Pixel Farming (Pixel Farming Robotics, 2025) and Weedbot (WeedBot, 2025),

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among others.

This article focuses on the search for solutions for the selective treatment of weeds in the early stages of cultivation, when crops are most vulnerable. Damage caused during initial growth, as well as nutrient deficiencies, can lead to lower yields and reduced final production. This deficiency, as previously mentioned, is often due to the parallel growth of weeds alongside the target crop. In the search for alternative methods of weed control, the creation of a laser module is proposed. This module, integrated into an autonomous platform, would enable selective and safe weed removal without risks to humans or the environment.

The article begins by detailing the materials and methods employed throughout the project. It then presents the design of key components, including the laser treatment system and the motion control mechanism. Furthermore, it provides an in-depth analysis of the power requirements, positioning accuracy, and treatment time associated with the system. Finally, the article concludes with the proposal of a protective housing and the final assembly approach, ensuring both functionality and user safety.

2 MATERIALS AND METHODS

The development presented in this article is, so far, a theoretical model aimed at demonstrating the feasibility of a modular laser-based system for selective weed removal during the early stages of crop growth. The design focuses on creating a cost-effective and easily adaptable structure that can be integrated into an autonomous robotic platform.

For this purpose, the RB-VOGUI platform by Robotnik has been used as the base for development; an example of which can be seen in Fig. 1 (S.L.L., 2025). This platform was selected due to its versatility, robustness, and proven capabilities in agricultural environments. The proposed module has been conceptually integrated into the platform's mechani-



Figure 1: RB-VOGUI platform.

cal and control architecture, considering its payload capacity, dimensions, and energy requirements.

Furthermore, for the design and mechanical calculations of the proposed modular structure, Autodesk Inventor 2015 was used (Autodesk, Inc., 2025). This software enabled the creation of detailed 3D models of the components and assemblies, as well as the performance of preliminary simulations to evaluate aspects such as structural integrity, weight distribution, and mounting feasibility on the proposed platform.

3 DESIGN APPROACH

The main objective of this paper is the design of a modular, low-cost structure that can be attached to an autonomous robotic platform and is capable of mobilizing a laser system to eliminate emerging weeds during the early stages of crop growth.

This section presents the final development of the proposal, addressing each of the key elements required in the project to achieve the main objective previously outlined. It details the specific steps for the selection and optimization of the laser, including the source and power necessary for effective weed treatment.

In addition, the design of the movement system and support structure is presented, with a focus on the calculation and implementation of the laser orientation mechanism.

Finally, the integration of the system into the chosen robotic platform is described, ensuring an efficient connection and operation that enables the precise and effective removal of emerging weeds during the early stages of crop growth.

3.1 Laser System

The first element to be dimensioned, and upon which all other developments of the project depend, is the laser module. One of the key aspects in the development of this project is the possibility for the resulting model to be low-cost compared to current developments. For this reason, combined with energy and space limitations, diode laser generation has been chosen as the source.

Due to cost constraints and the availability of commercial modules, the decision was made to seek an existing module on the market for implementation in the model. There are several factors that determine the laser's effectiveness for weed control. This relationship between these factors can be seen in Eq. 1

$$Dose\left(\frac{J}{mm^2}\right) = \frac{P(W) * T(s)}{A(mm^2)} \quad (1)$$

where:

- P is the optical power: The output power of the module. That is, the final power applied by the module to the weed for its eradication. This is the parameter to be considered when dimensioning.
- T is the exposure time: This refers to the time the laser pulse acts on the target weed. The longer the action time, the greater the amount of energy deposited on the plant matter.
- A is the area: This is the cross-section corresponding to the portion of the laser beam impacting the weed at a given height.

The main objective of using a laser is not the complete destruction of the weed, but rather halt its growth by damaging it. Some studies have already explored the amount of energy needed to achieve this and, in this way, determine the laser systems to be used. For this project, the result obtained by Andreassen et al. (2024) of 12.7 J/mm^2 will be used as a reference. This value refers to weeds that are at the two leaf stage.

With this value as a reference, the dimensioning and selection of the module depend solely on its optical power, since the beam diameter can later be adjusted as needed using lenses.

Given the range of power outputs, prices, and the reliability of each brand, the 40W module from XTool was chosen for the development of this project. The laser's minimum specified area is $0.1 \times 0.15 \text{ mm}^2$. Since this area is too small to accurately focus on the weeds, it is estimated that it will be adjusted to 1 mm^2 . Therefore, based on the previous data, the required exposure time, per weed, is:

$$\text{Time}(s) = \frac{12.7 \frac{\text{J}}{\text{mm}^2} * 1 \text{mm}^2}{40\text{W}} = 0.31\text{s} \quad (2)$$

Given the previous treatment time per weed, it has been theorized that the positioning time for the laser could not exceed the 50% of the total treatment time. This is so that the robot can achieve a dynamic treatment, that is, while moving.

3.2 Detection System

Alongside the laser module, another element of importance for the proper functioning of the project is the weed detection system. This system allows monitoring the work environment, detecting the weeds, and classifying them for the subsequent action of the movement system and the laser responsible for the treatment.

There are different alternatives when it comes to capturing the necessary information from the environment for later processing. The main characteristic that this type of system must fulfill is to allow 3D positioning of the weeds for more efficient processing and more accurate detection of their morphology (Kateris et al., 2021). For this project, due to the popularity of this system in similar applications, as well as its key features and ease of use, the ZED 2 camera is proposed as the spatial capture system. It can be seen in Fig. 2.



Figure 2: Capture system, ZED 2.

In summary, the combination of stereo-vision, high-resolution image capture, and real-time processing makes the ZED 2 an ideal candidate for the development of this project in weed treatment, being a powerful and effective tool.

3.3 Position and Targeting System

This subsection addresses the design and development of the support structure for the laser module, as well as the movement and orientation system of the laser necessary for weed treatment. Additionally, structural analyses will be conducted, taking into account considerations such as weight and strength, as well as the integration of the module assembly into the main structure of the tractor vehicle.

Firstly, for the correct integration of the main structure onto the module, an intermediate element was developed. This element consists of a 10 mm thick aluminum plate that covers the entire upper part of the RB-VOGUI. In addition, this aluminum plate is perforated with various patterns of threaded holes of different diameters. The creation of these patterns was carried out with other projects in mind, as well as to allow the integration of any additional components that may be required during the development of this project. This intermediate element can be seen in Fig. 3.

To ensure the modularity of the structure, as well as to keep the weight and cost low, standardized 30x30 Bosch support profiles have been chosen. The use of this type of profile guarantees the possibility of integrating any component in a quick, simple, and robust manner. In turn, the availability of standard elements for assembly ensures that the resulting structure is simple yet strong, capable of withstanding harsh working conditions and meeting the requirements of

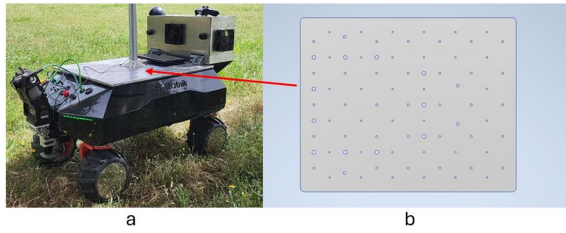


Figure 3: Integration Element. a) Mobile platform. b) Integration plate.

the laser module's movement system.

To ensure proper integration with the mobile platform, as well as to simplify the design and guarantee a sturdy structure, the design shown in Fig. 4 is proposed.

Concerning the selection of the targeting system, it plays a decisive role in determining the project's performance. An evaluation was carried out of different mechanisms commonly used in the literature for orienting the laser beam onto the weeds: cartesian, angular and mixed, among others. Firstly, a mixed configuration was ruled out, as it would complicate both the current design and its subsequent control. Among the remaining options, the Cartesian system was selected for this purpose due to its simplicity, both in terms of design and control.

Within the Cartesian movement typology, there are some variants that enable smoother and faster motion compared to traditional versions. One of these variants is known as Core XY. This system uses two stepper motors to achieve the movement of the head through a specific arrangement of belts and pulleys, so that motion along the X and Y axes results from the combined rotation of both motors. The belts in this system are crossed, allowing for fast and stable movements, as can be seen in Fig. 6.

In addition, this architecture reduces the vibrations and torsions typically found in other Cartesian variants, providing high precision and stability. This configuration is widely used in other applications, such as 3D printers (Goszal et al., 2021; Soon et al., 2020; Vasquez et al., 2020).

For the integration of this movement system into the previously designed structure, the design of custom parts is proposed to incorporate the necessary standard components. Firstly, each of the two motors responsible for the movement must be positioned at different heights to avoid interference in the movement of both belts. Additionally, the design must allow for the incorporation of pulleys that enable the belts' displacement. The motors selected to drive the Core XY mechanism are two standard 42x42 mm Nema 17 motors (Community, 2025).

At the same time, these motors must be mounted

onto the structure, maintaining a fixed position at varying heights, as mentioned earlier. From this point on, references to both motors and their mounting assemblies will follow the naming shown in Fig. 7.

The final design of both assemblies can be seen in Fig. 8 and Fig. 9, representing the left and right motor assemblies respectively.

Finally, the connection of all the components that form the Core XY mechanism is proposed through two separate belts. Each belt is positioned at a different height to prevent interference between them. In addition, the pulley system is designed to avoid unnecessary friction and to keep the entire working area of the module clear. The final result of the implementation can be seen in Fig. 5, where both belts and their path along the structure can be observed.

4 RESULTS

This section presents a brief discussion of other key elements to consider in the design for its future operation. One of these elements is the speed at which the laser is expected to operate, so that the working time can be estimated, as well as its mode of operation, that is, whether the mobile platform can move and carry out the treatment dynamically or, on the contrary, must stop each time the treatment is to be applied.

First, it is necessary to take into account the characteristics of the selected Nema 17 motors. It is shown that the nominal speed achievable with this type of motor reaches up to 1000 rpm, enabling high speeds. An estimate can be made of the maximum linear speed, under no load, of the belt driven by the motor. To do this, it is first necessary to convert this rpm value into linear speed using the following equation:

$$v = \omega * r \quad (3)$$

Where ω is the angular velocity in radians per second (rad/s) and r is the radius of the pulley driven by the motor. Converting rpm to radians per second gives:

$$\omega = \frac{1000 * 2\pi}{60} = \frac{1000 * \pi}{30} \approx 104.72 \text{ rad/s} \quad (4)$$

Given the pulley's diameter of 12.2 mm:

$$r = \frac{12.2 \text{ mm}}{2} = 0.0061 \text{ m} \quad (5)$$

From which the lineal velocity is obtained:

$$v = 104.2 \frac{\text{rad}}{\text{s}} * 0.0061 \text{ m} \quad (6)$$

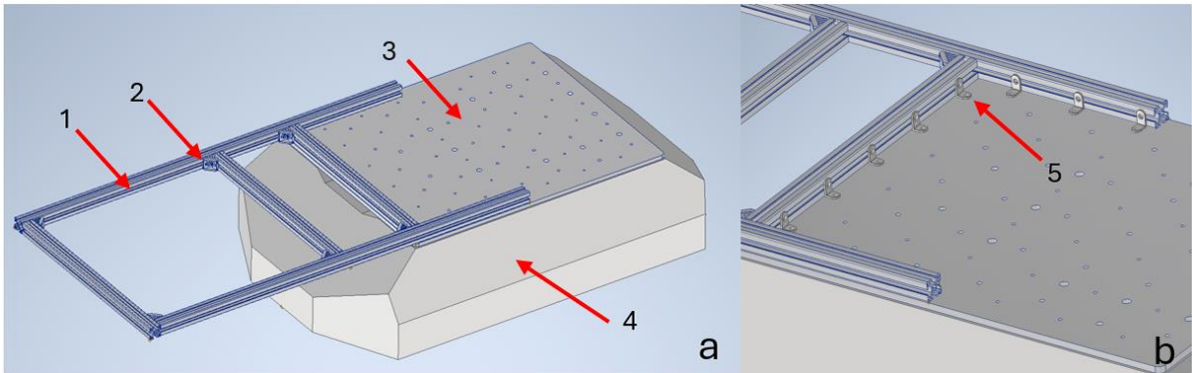


Figure 4: Structure integration. a) Main assembly (1. Bosch 30x30 profiles, 2. Corner joint, 3. Integration plate, 4. RB-VOGUI). b) Detail of the integration with the perforated plate (5. Fasteners).

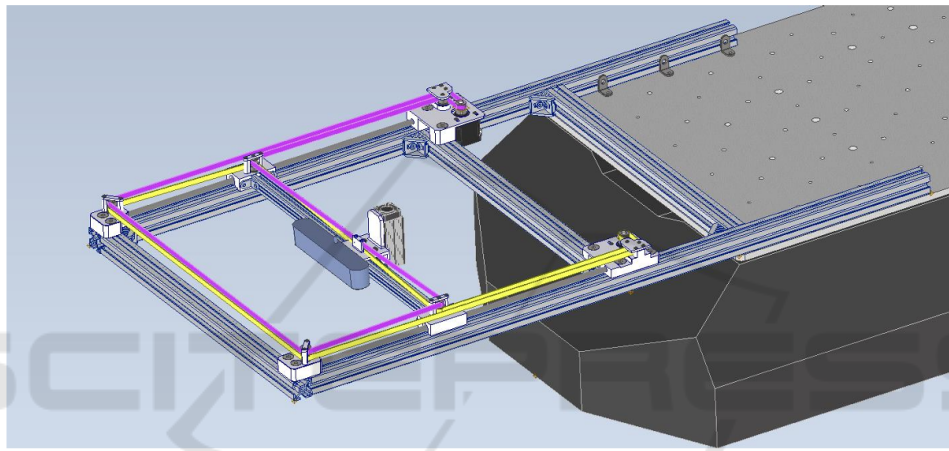


Figure 5: Complete assembly of the structure and movement system.

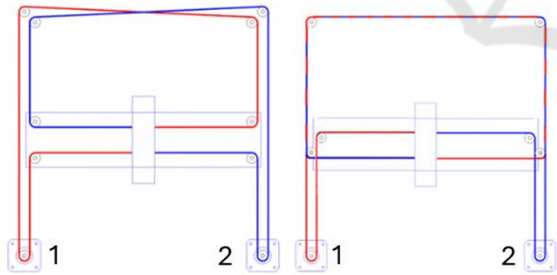


Figure 6: Core XY diagram. The image on the left shows an expanded version of the figure on the right to facilitate understanding of the paths of the different belts.

$$v \approx 0.635 \text{ m/s} \quad (7)$$

Therefore, the maximum linear speed of the belt in no-load conditions is approximately 0.635 m/s. This performance is similar to other assemblies with comparable characteristics and loads, as seen in 3D printers like the Ultimaker S5 or the Kingroon KLP1, achieving travel speeds of up to 400 mm/s. Based on this, an example treatment is proposed. With it, an estimate of the treatment time required to clear a

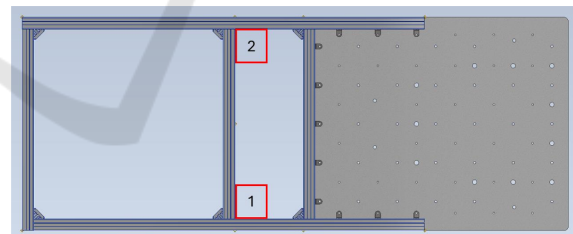


Figure 7: Placement and designation of both motors.

specific area can be made. Fig. 10 shows a real example of weed detection from the WeLaser project system (WeLaser Project, 2024) as an application case. The box in the image is approximately 500 mm wide, allowing an estimation of the distances between the various detected weeds.

The path needed to connect each point to the next can be obtained by first computing the optimal sequence using algorithms such as the Traveling Salesman Problem (TSP). Then, path-planning algorithms like D^* can be used to compute the shortest path between each pair of consecutive points, especially in

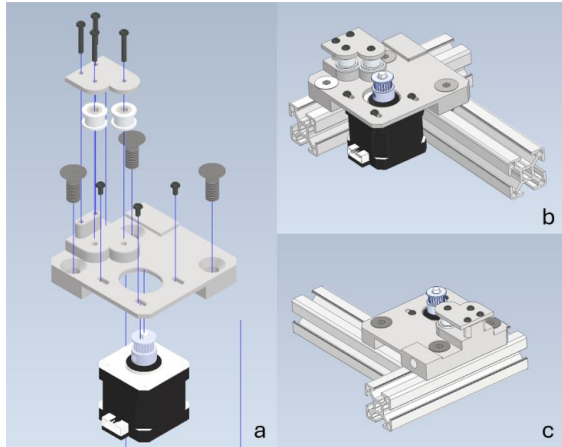


Figure 8: Motor 1 assembly. a) Exploded view. b) Rear view. c) Front view.

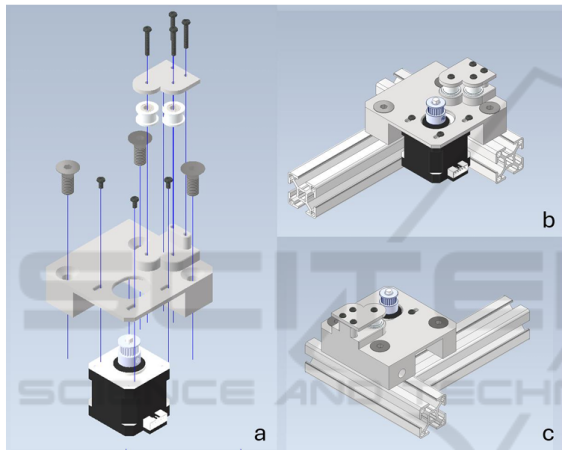


Figure 9: Motor 2 assembly. a) Exploded view. b) Rear view. c) Front view.

dynamic environments where the terrain may change the weed's position and orientation.

Assuming the necessary laser exposure time (t_e) previously obtained as 0.31 seconds, the total time required for the example treatment of the weeds detected in the previous image, at 400 mm/s, is obtained as follows:

$$\text{Total distance}(D) = \Sigma D^* = 580\text{mm} \quad (8)$$

Which, using the obtained speed in Eq. 7 is:

$$\text{Travel time}(t) = \frac{D}{\text{speed}} = \frac{580\text{mm}}{635\text{mm/s}} = 0.91\text{s} \quad (9)$$

Combining both, treatment and travel times:

$$\text{Total time}(T) = t + t_e = 0.91\text{s} + 7 * 0.31\text{s} = 3.08\text{s} \quad (10)$$

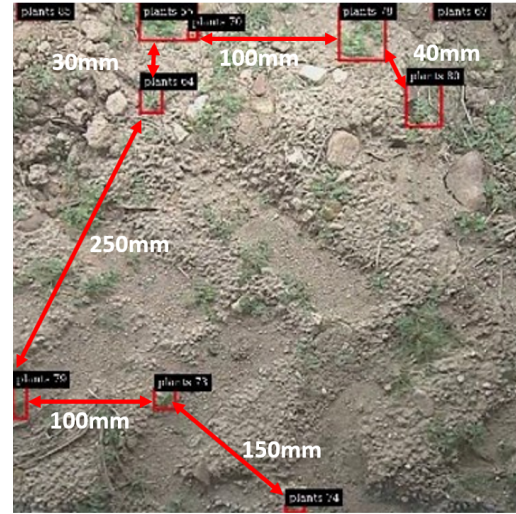


Figure 10: Example of weed detection.

In this example, the travel time, 0.91s, represents only a 30% of the total treatment time, complying with the previous hypothesis.

This obtained time demonstrates the efficiency of the design, allowing, although at low speeds, the dynamic treatment of the weeds. That is, as the mobile platform is guided over the target crop, the proposed module will be able to eliminate the weeds as they are detected. It is important to keep in mind that oscillations caused by irregularities in the terrain may lead to deviations in the system's accuracy and should be addressed in future studies. Additionally, thanks to the precision of the 1.8° Nema 17 motors, a laser positioning accuracy of the following is expected:

$$\text{Linear accuracy} = \text{Angular accuracy} \frac{C}{2\pi \text{ rad}} \quad (11)$$

Where C is the circumference of the pulley.

$$C = 2\pi r = 2\pi * 6.1\text{mm} = 38.36\text{mm} \quad (12)$$

From which it is obtained:

$$\text{Linear accuracy} = 0.0314\text{rad} \frac{38.36\text{mm}}{2\pi \text{ rad}} = 0.192\text{mm} \quad (13)$$

Therefore, since no reduction is found during the established travel of the belts, a theoretical positioning accuracy of less than 0.2 mm is expected for the laser on the weed. It is important to keep in mind that this value will most likely be altered in real-world scenarios, although a millimeter precision is still expected.

Finally, it is important to take into account the energy consumption of the system, since it is expected that, together with the mobile platform, they

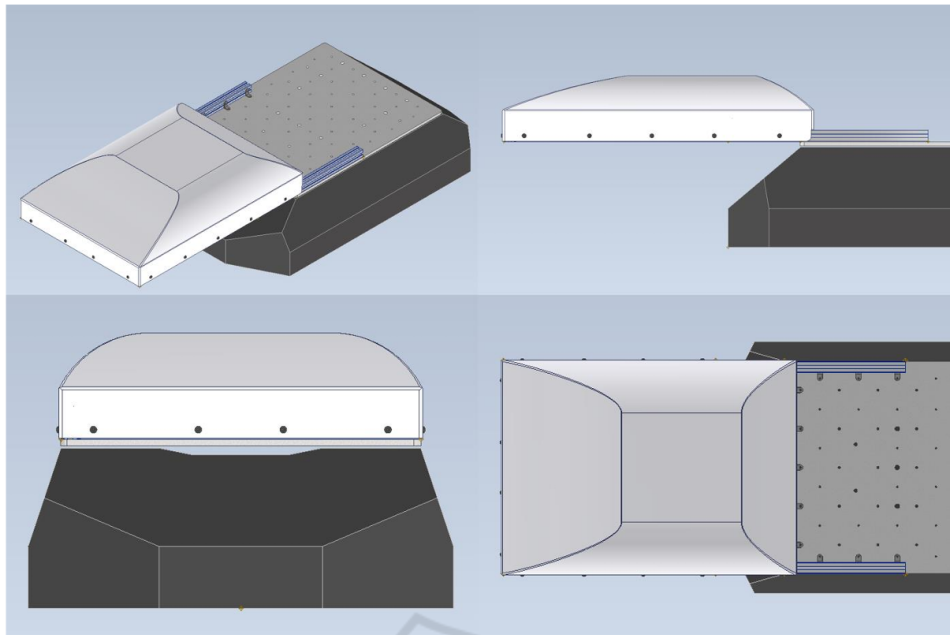


Figure 11: Proposed housing design.

will carry out the treatment autonomously; for this, it must be powered by the batteries that can be included within the mobile platform. Below, in Table 1, a breakdown of the main approximate energy expenditures, as well as the total, considering only the main components, is shown.

Table 1: Power usage.

Component	Qty	Power/unit	Total Power
Laser Module	1	144 W	144 W
ZED2	1	4.5 W	4.5 W
Nema 17	2	7.25 W	14.5 W
Mobile Platform	1	4 × 400 W	1600 W
Total Power			1762.98 W

Finally, a housing design has been proposed to enclose the system and ensure user safety. The final housing consists of a single piece that fits over the base structure and is attached to it using 14 M6 screws fastened to the Bosch profiles that make up the frame. Additionally, it is designed with a 1mm clearance over the structure to avoid any assembly issues caused by tolerances in other components or by temperature variations.

The rear part of the housing is semi-open, allowing the structure to connect to the integration plate while keeping the area where the laser operates covered. In this way, any direct reflections of the laser from the inside are prevented. This proposed design

can be seen in Fig. 11.

In line with this safety approach, the entire bottom area remains open. If necessary, and to prevent harm to operators during system control, flaps or any other protective elements can be installed around the structure down to the ground, thereby avoiding any unwanted reflections of the laser beam.

5 CONCLUSIONS

In this paper, the primary objective has been successfully achieved: to serve as a foundational exercise for future research endeavors. The approach has proven to be a highly suitable tool for acquiring the necessary knowledge for such tasks, while also providing a conceptual framework that can be applied in the field of laser-based weed treatment. From the perspective of agroecology, such innovations can promote more sustainable agricultural practices by reducing reliance on chemical herbicides. Integrating this technology within ecological farming systems may help preserve soil health, biodiversity, and long term productivity. The results presented, along with the methodology followed, are consistent with what is expected in a research-oriented study, contributing to the advancement of Agriculture 4.0 technologies.

Regarding the specific objectives of the proposal, the design and development of a modular structure have been accomplished, offering high flexibility and scalability. This demonstrates the feasibility of cre-

ating an efficient and cost-effective structure that is also highly adaptable and capable of being updated as needed. The modular approach and the use of standardized components not only reduce manufacturing costs but also facilitate future maintenance and system upgrades.

Additionally, an appropriate laser module has been successfully selected. As the core component of the system responsible for delivering treatment to the weeds its selection was critical. After analyzing several available options, a laser was chosen that balances power and precision, ensuring effective weed elimination while avoiding damage to surrounding crops. Future research should focus on constructing a real model, in order to analyze and compare the previously obtained accuracy and speed.

Overall, the project has met all its intended goals, enabling the development of a modular, economical, and efficient system for laser-based weed control. Furthermore, this work contributes to the ongoing research in this area by providing a solid foundation for future studies and technological developments.

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