Agrofelis Robot documentation handbook

Multipurpose Energy-Dense, Implement Carrier Agricultural Robot.

Agrofelis

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Abstract

The Agrofelis robot is a multipurpose agricultural robot which is low cost, energy dense, programmable, AI-ready and precision agriculture capable. The vast majority of agricultural cultivation comprises small farms less than 2 hectares. Automated machinery that can bridge the gap between hand-held tools and tractors, are most suitable for such farms. The Agrofelis base vehicle can be used as a carrier of various implements such as grass cutter, turbine sprayers, fog sprayers, fertilizer spreader and other tools. The Agrofelis robot could offer a mechanized solution which incorporates an array of sensors, like lidar, hall sensors, gyroscopes, motion feedback and camera. The fabrication of the robot uses simple materials and commercially available components. The robot can be easily reproduced in single units or small batches by following the documentation.

Contents

Agrofelis Robot

The Agrofelis Robot is a multipurpose agricultural robot which is energy dense programmable AI-Ready and precision agriculture capable.

Figure 1: Agrofelis Robot in the vineyard with a pulse jet fogger

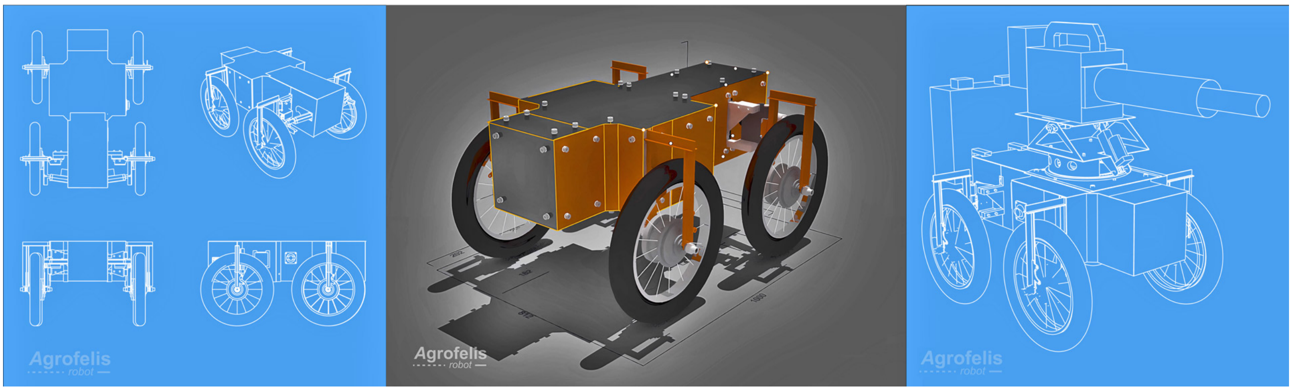

Figure 2: Agrofelis Robot schematics

Figure 3: Agrofelis Robot in the vineyard downhill with a pulse jet fogger

The Problem

The convergence of declining demographics, economic disparities, rising energy costs and supply chain disruptions in the West and the looming specter of climate change has created a perilous confluence of issues particularly impacting agriculture and public safety.

In the agricultural sector, farmers are experiencing growing difficulty finding seasonal farm workers while also having to deal with the escalating costs of cultivation, which results in marginal profits, unharvested crops, and even abandoned farms. To combat these hurdles, there is an urgent need for an affordable and efficient platform that bridges the gap between traditional tractors and handheld tools and multiplies an unskilled farm worker's productivity. This imperative solution is crucial for small-scale farmers in order to safeguard their existing agricultural capital.

Moreover, the repercussions of climate change have increased the likelihood of wildfires. As fire departments confront more frequent fires, the necessity for an affordable vehicle that can serve in an integrated role with firefighting units in rural areas to reduce workloads and provide standoff safety from heat exposure is critical. A production line for firefighting robots could prove a real business challenge because of low utilization of the vehicles (typically under 100 hours/year), and a number of fire fighting departments have resorted to DIY solutions.

Existing vehicles on the market that can serve as adaptable platforms for various tasks are either prohibitively expensive or just not available. So it is essential to offer the ability of manufacturing a low-cost base vehicle within local machine shops, in single units or small volumes, that has a small footprint, is energy dense and agile and holds the potential to tackle localized challenges in agriculture and public safety sectors. The proposed, prototyped and open-sourced robotic vehicle system attempts to address those needs through the variety of applications in those fields in the lowest possible cost and could be utilized and manufactured by individual farmers, agricultural cooperatives, fire departments, municipalities, and beyond.

The Technology Considerations

The majority of technical solutions proposed for agricultural robotic systems aim for high levels of autonomy by using satellite positioning systems such as RTK GNSS (Real-Time Kinematic Global Navigation Satellite Systems), cameras and LIDAR sensors for achieving Simultaneous Localization And Mapping (SLAM), as well as supplementary systems like radars, odometers and inertial systems.

In the case of RTK GNSS, signal interruption due to foliage, weather conditions, or a lack of ground stations limits its usefulness. LIDAR, on the other hand, can be combined with odometers, cameras and IMUs, with no reliance on external signals. Additionally, the use of cheaper 2D LIDAR on a tilting mechanism allows 3D coverage with considerably lower cost. The strategic selection of LiFePO4 batteries offers endurance in high temperatures, in-combustibility, utilization of non-toxic materials, the ability to work unevenly charged and a slow rate of self-discharge. Introducing a remote control system capable of automating certain operations through recording and replaying can offer an affordable alternative suitable for smaller platforms, while also having a broader applicability and offering a considerable boost in overall productivity.

The Potential

Within the scope of an agricultural vehicle, a variety of technologies could be integrated, encompassing implements such as:

- Grass Cutter/Lawn Mower: A frequent and necessary application in orchards.
- Turbine Sprayers: Beneficial across orchards and vegetable cultivations for dispensing pesticides or water-soluble fertilizers.
- Fog Sprayers: Enabling extended reach amidst dense foliage and providing antifreeze protection with glycerin oil.
- Fertilizer Spreader: A copious job essential for both orchards and vegetable crops.
- Sensor Suite for Plant Data Collection: Facilitating comprehensive plant data acquisition, including diagnoses of plant diseases.
- Mechanized Weed Elimination: Using mechanical, laser or microwave mechanisms for weed control.
- Robotic Picking Arm Base & Power Hub: Applicable for low-lying plant cultivations and greenhouse environments.
- Power Hub for Fruit Picking Drones (e.g. similar to Tevel technology).

Similarly, the technologies that could be incorporated on a public safety vehicle could include applications like:

- Firefighting Gear Carrier.
- Standoff Fire Hose Base.
- Tethered Drone Base for Enhanced Situational Awareness (akin to Elistair technology).
- Sensor Suite for Patrolling and Surveillance.

The potential of having the ability to create an open-source base robotic vehicle, adaptable across a wide range of applications and tools offers significant versatility.

The Project

The chassis of the vehicle was designed with field agility, cost reduction and manufacturing simplicity in mind. The project recommends the particular chassis as a baseline, it is assumed though that users might opt for different chassis parameters like the addition of suspension or different wheels. The Robot vehicle's core is an open-source programmable system that could potentially migrate in various mechanical platforms either for motion control or for implement control, while also having programmable automation capability and retaining the capability for precision applications and AI readiness.

The chassis implemented for the project is a carrying bar welded chassis with detachable components. It boasts a maximum carrying capacity of 250 kilograms of payload and for cost efficiency eschews suspension. A four wheel drive system is employed with energy efficient in-hub motors that are dynamically regulated through real-time feedback sensors. The steering system is composed of two independent linear actuators driven with mechanical and energy monitoring sensors.

The power system boasts an energy autonomy of 8.0 kWh, conveniently fitting within a 1-square-meter space. It is composed of 8-element LiFePO4 batteries rated at 302 amps, paired with an intelligent battery management system at 250 amps discharge rate capacity and a data link enabling the utilization of energy-related indicators.

The processing elements of the system are modularized systems composed of Arduino or ESP32 modules connected with their relevant sensors and actuators acting on real-time adaptations, while being orchestrated via a Jetson Nano GPU running on Linux and using Web Sockets to allow implementation for interconnecting current and future components. A high-speed camera connected to the Jetson Nano enables the vision modality, augmented by a Coral AI accelerator, allowing machine vision tasks to be performed on the edge. A high-throughput drive (with read/write speeds of 250 MB/s) equips the system with 128GB of storage, enabling the robot to record and recall a substantial amount of offline and online data.

Furthermore, the project implements a two-degrees-of-freedom actuator rotating base, for attaching a thermal pulse jet fogger to the top of the robotic vehicle.

In addition to its wired infrastructure, the system supports a range of connectivity options, including Bluetooth for local wireless attachments, WiFi for nearby controllers, mobile phones and/or modules.

Presentation video

This video presents Agrofelis Agricultural Robot. A Multipurpose Energy Dense, Implement Carrier. A Programmable, AI ready, Precision Agriculture base vehicle.

Specifications

The Agrofelis robot operation specs are described below.

Dimensions

The Agrofelis Robot has been designed with narrow fields in mind. The purpose is to navigate in narrow rows as well as under low tree canopy.

Vehicle size	Value
Width	785 mm
Length	992 mm

Vehicle size	Value
Height	497 mm
Ground clearance	275 mm
Wheels diameter	440 mm
Wheels width	76 mm
Footprint	0.78 sqm

With the Rotating Implement Mount module and the thermal Fogger, the dimensions differentiate as follows.

Sizes with Fogger	Value
Length	1615 mm
Height	1044 mm

Mobility

The robot has adequate mobility to tackle most of the terrain in the agricultural fields. The loads that it can handle supersede what one would expect for its small size.

Mobility type	Value
Ascension	30 % grade
Descension	40 % grade
Towing capacity	1,225 kg
Carrying capacity	250 kg
Maximum tilt	32 degrees
Minimum speed	0.2 km/h
Maximum speed	5 km/h
Torque	144 NM
Weight	152 kg
Breaking	E-breaking and disc-brakes
Turning radius	1.04 meters

Thermal envelope

The thermal operating range that manufacturers give for each component of the robot is quite wide. Here are the numbers.

Component	Min temperature Celsius	Max temperature Celsius
Batteries	-35	65
BMS	-20	70
Motors	-20	70
Esp32 Wroom	-40	105
Arduino Mega	-40	85
Jetson Nano	-25	80
Google Coral	-40	85
Lidar	-10	40
Tires	-20	65

Electrical

Here are the capacities and consumption of the full electrical system.

Component	Type	Value
Battery	Min volt	20
Battery	Max volt	29.2
Battery	Amp	302
Battery	Amp	302
Battery	Charge	0.5 C
Battery	Charge	1 C
BMS	Discharge	250 Ah
Motors	Consumption	1000 Watt
Steering System	Consumption	20 Watt
Servo breaks	Consumption	30 Watt
Jetson Nano	Consumption	17 Watt
Google Coral	Consumption	3 Watt
Relays	Consumption	8 Watt

Mobility tests video

The Agrofelis Robot is evaluated on Extreme Mobility Events, including towing and carrying high load, as well as acceding a high degree slope. Get ready to be surprised with its performance !

Documentation overviews

In the following sections, the detailed documentation of all developed modules constituting the Agrofelis robot, are referenced along with their abstracts and figures highlights. The documents present the rational of each module, how they are decomposed into sub parts and sub-components, how to reproduce them by following step wise procedures using schematics and photos taken during their fabrication. The documents moreover provide indicative suppliers and total cost estimations. The documentation is referenced in github and their PDF rendering are moreover concatenated in this book, enabling to have the full Agrofelis documentation in one file that can be printed and viewed consistently using the Portable Document Format standard.

Agrofelis Chassis Frame Design and Fabrication

The chassis frame design and fabrication document focuses on the manufacturing details of the vehicle's frame. The frame houses and protects the 8 kw power module with its LiFePO4 batteries, the electronics, the sensors and actuators of the unmanned vehicle. The frame was implemented using a total of 7.35 meters of 20X20 mm regular square iron bars, it establishes key placeholders for mounting the detachable wheels, the protective covers and via its grid-like attachment points enables mounting anticipated tools, as well as future ones. The primary design considerations were footprint minimization, battery compartment protection, chassis rigidity, and ease of manufacture utilizing low-budget tools and readily available materials.

The complete documentation of the Agrofelis chassis frame is provided below.

- Chassis frame design and fabrication

An indicative selection of figures from the Agrofelis chassis frame design and fabrication document, is summarized by the following figure.

Figure 4: Agrofelis chassis frame design and fabrication figures highlights

Agrofelis Robot Wheels Fabrication

This Agrofelis robot wheels fabrication document presents a comprehensive overview of the manufacturing process behind the four-wheel drive (4WD) system of the Agrofelis robotic vehicle. It begins by detailing the specific requirements and then progresses to the completed fabricated solution. The design plans, compilation procedures, assistance assets and images taken throughout development are presented in a step-by-step manner. The sub-components composing four Agrofelis wheels are indexed with their unit prices and overall cost, along with references to indicative suppliers.

The complete documentation of the Agrofelis robot wheels fabrication is referenced below.

- Agrofelis robot wheels fabrication

In the figure below, we showcase a condensed compilation of the four most illustrative images extracted from the document, highlighting the process of manufacturing the four-wheel drive system.

Figure 5: Agrofelis robot wheels fabrication figures highlights

Agrofelis Robot Forks Design and Fabrication

The wheels forks design and fabrication document presents a progressive overview of the fabrication process for the forks mounting the four wheels of the Agrofelis vehicle. These forks are intentionally designed to be detachable, so that the wheels could be removed or replaced with alternative ones. The forks are responsible for securing the active wheels of the vehicle, establishing active brakes actuated via servos, enabling steering and installing feedback rotating mechanisms. Two types of forks are being employed, those installed in the front and those installed in the back. The majority of fork designs are similar, with the only differentiating factor being the mounting mechanism aimed for fixed or steering purposes. The forks installed on the left and right sides are arranged in a mirrored fashion. The forks are constructed from regular iron T-shaped rods that have been cut and welded. Additional sub-components elaborated are the vehicle's fork mounting mechanisms and the parrot-like (drop out) elements securing the wheels via the motor's hub shaft. The design schematics, plasma cut patterns, as well as images of the fabrication progression are all documented. The document concludes by providing a list of indicative suppliers from whom the raw materials were acquired, further enriched with bill and material details.

The complete documentation of the Agrofelis wheels forks is provided below.

- Wheels forks design and fabrication

An indicative selection of figures from the Agrofelis forks design and fabrication document, is provided by the consequent image.

Figure 6: Agrofelis wheels forks design and fabrication figures highlights

Agrofelis Power System Design and Fabrication

The power system design and fabrication document delves into the power-related components that classify the Agrofelis robot as an energy-dense solution. The battery technology employed, as well as the capacity, management, monitoring, and charging options, are elaborated. The battery arrangement for minimizing the vehicle's footprint, as well as its protective enclosure and cable connectivity schematics, are all documented. In addition, the power distribution, the different voltages energizing the various electronics, along with the protective mechanisms are documented. Furthermore, the document describes the WiFi relays and how to make them more robust. The documentation also lists all the utilised components, their prices, along with indicative suppliers facilitating the reproducibility of the system.

The complete documentation of the Agrofelis Power System is provided below.

- Power system design and fabrication

A selection of figures from the Agrofelis Power System documentation, is presented by the following figure.

Figure 7: Agrofelis steering system design and fabrication figures highlights

Agrofelis Protective Covers Design and Fabrication

The protective covers design and fabrication document builds on the Agrofelis frame design and fabrication documentation by detailing the protective covers of the vehicle, including their schematics and the source code files utilized for a CNC plasma cutter. Additionally, photographic material offers insights into the manufactured parts. A list of components and indicative suppliers that comprise the bill and material information for isolating the robot from its external environment, is documented.

The complete documentation of the protective covers is provided below.

- Agrofelis protective covers design and fabrication

An indicative selection of figures from the Agrofelis protective covers design and fabrication document, is summarized by the following figure.

Figure 8: Agrofelis protective covers design and fabrication figures highlights

Agrofelis Steering System Design and Fabrication

The Agrofelis steering system design and fabrication document delves into the intricacies of the Agrofelis vehicle's steering system. The design rationale, structural elements, feedback mechanisms and the custom PCB board are all presented and documented in detail. The document encompasses source code files, key design metrics, schematics, 3D printed assets, laser-cut NC files and photographs, offering a view of the fabricated components and manufacturing steps in a progressive manner. The steering module of Agrofelis enables it to make a tight 1-meter turn radius and its design minimizes the overall footprint of the vehicle. The document also contains a list of components and indicative suppliers that comprise the bill and material information of the steering module. Finally, the documentation provides an overview of the implemented driver software, its classes, and their relations.

The complete documentation of the Agrofelis steering system design is provided below.

- Steering system design and fabrication

A cherry picked selection of figures from the Agrofelis steering system design and fabrication documentation, is presented by the following figure.

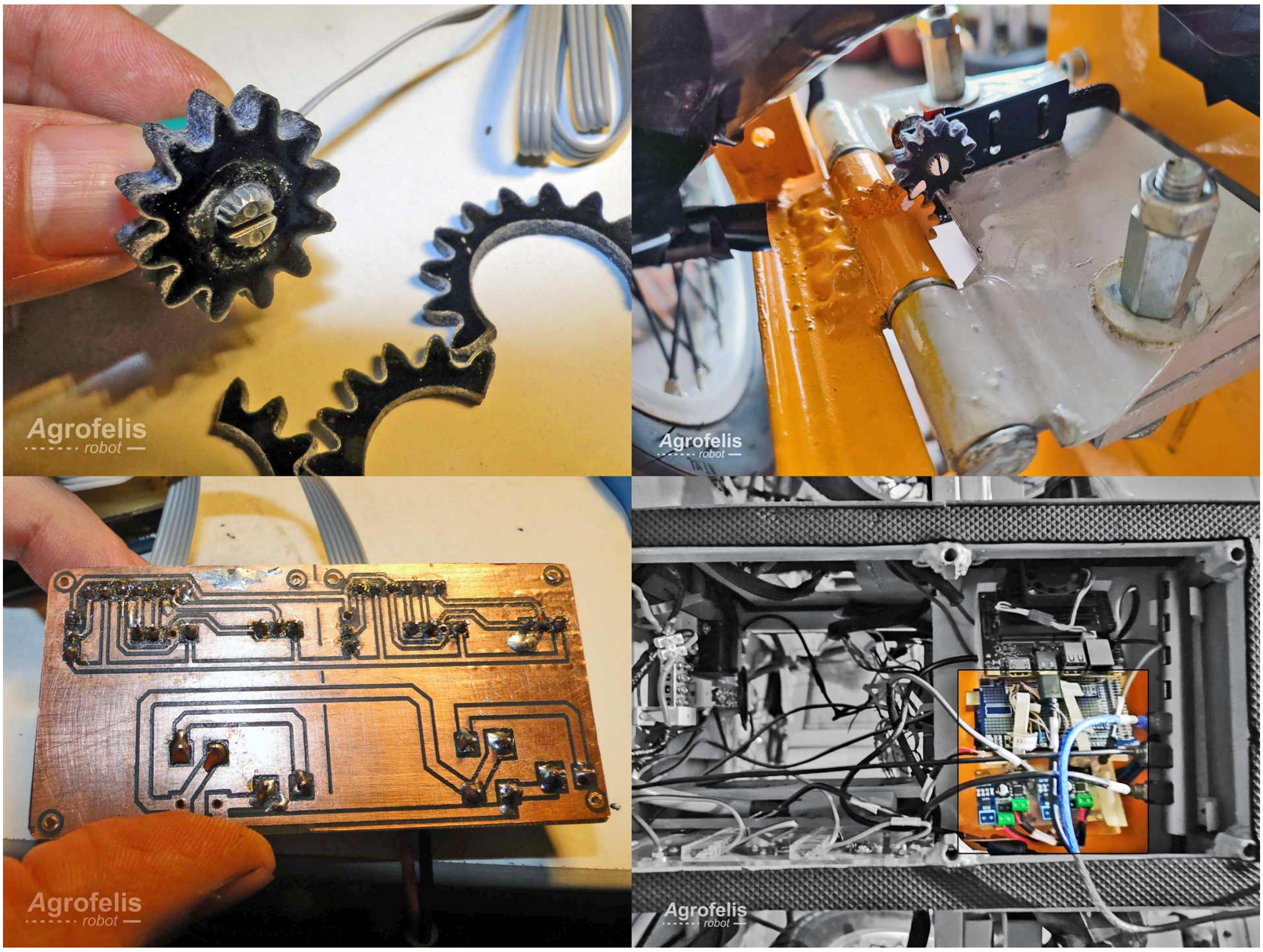

Figure 9: Agrofelis steering system design and fabrication figures highlights

Agrofelis Motors Hub Driver Design and Fabrication

This motors hub driver document delves into the manufacturing and functional intricacies of a composite module tailored for controlling and sensing a pair of in-wheel motor hubs digitally, over the air. The documentation decomposes the different elements involved into sub-modules, into their sub elements in an organized and progressive manner. A detailed exposition of each component's rationale and its seamless integration with counterparts is provided, bolstered by design plans and photographic evidence of the actual implementation. The document offers a roadmap through the Agrofelis repository, elucidating the source file locations and the production processes underpinning the manufacturing of the Agrofelis Motors Hub Driver. The document presents the structural elements of the unit, the three type of PCB sub-components, the software running on the micro-controller, key tools employed in the manufacturing process and ends with a compendium of indicative suppliers to purchase the different parts.

The complete documentation for the motors hub driver module is provided below.

- Motors hub driver document

In a nutshell, the *Motors Hub Driver module* goes over the electronic sub-modules, which include the motors hub controller, power, and ADAC modules. The motors hub controller module processes signals, wirelessly controls actuators, and manages motor hubs through ESP32. It reads analog driver hall sensors via an ADAC module, senses motor conditions, and regulates power, speed, and direction. The motors hub power module handles the motor hub driver, incorporating relays, current sensors, and logic level converters, while the motors hub ADAC module facilitates sensor interfacing and uses external ADC for analog channel expansion.

A representative depiction of the progression in crafting the motor hub driver is showcased by the following highlights figure.

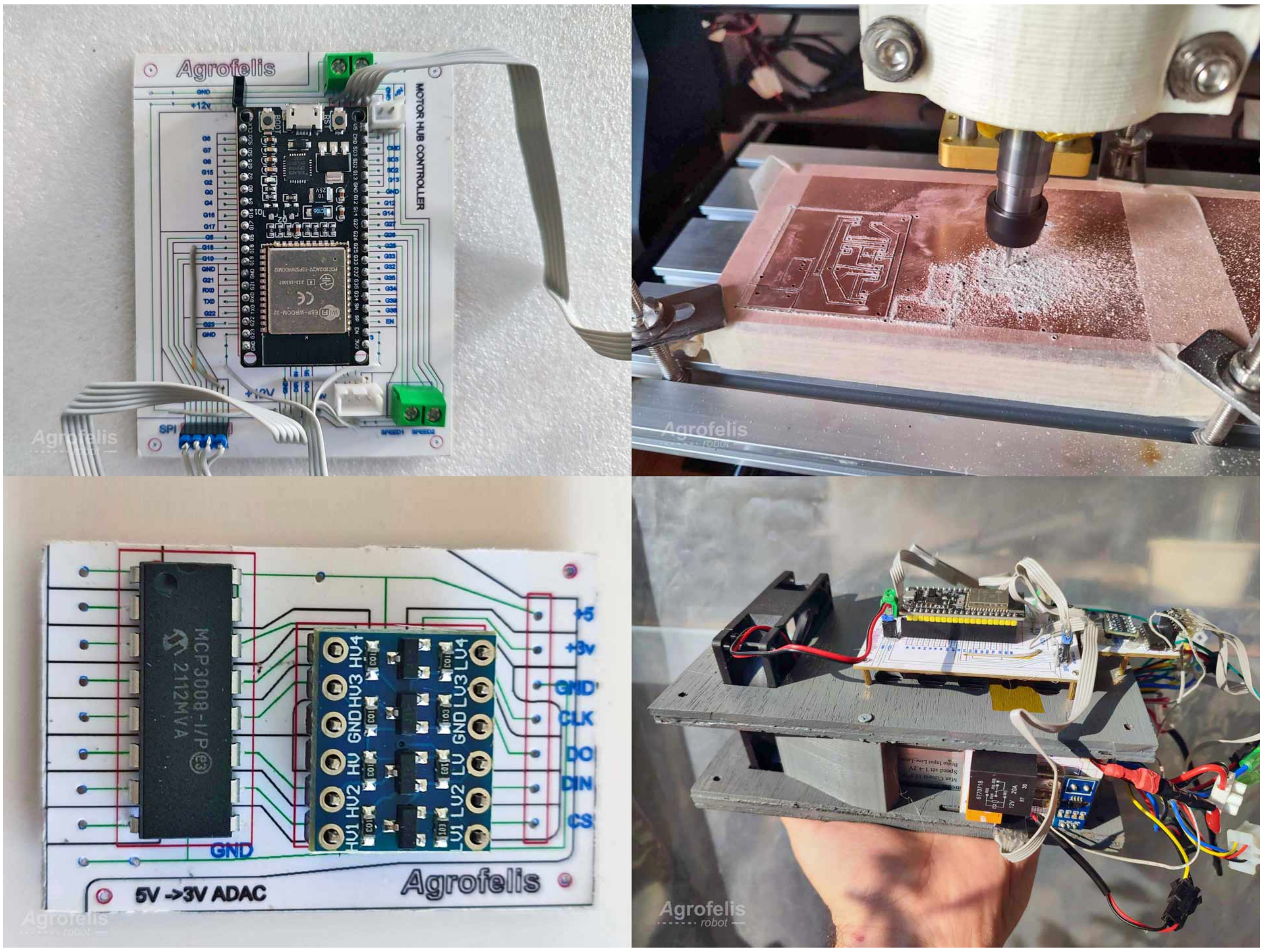

Figure 10: Agrofelis motors hub driver figures highlights

Agrofelis 3D Lidar Front Sensors Design and Fabrication

The 3D Lidar front sensors design and fabrication document details the creation of the front sensors module, which is used to install a 3D Lidar mount on the Agrofelis robot, enabling it to have spatial awareness of its surroundings. The module comprises an ESP32, an ESP32 Terminal Adapter, a Servo, a Lidar, an MPU and a GPS sensor. The ESP32's primary role is to process Lidar serial data, gather motion sensor and GPS data and pass their information over the USB bus. The module facilitates the tilting of the 2D Lidar to capture multiple planes of 360-degree coverage , effectively creating a spherical 3D view of its surroundings. The rationale behind the module, its schematics, the manufacturing process, the software controlling the module and reflecting its information, as well as a Lidar data analysis tool developed, are all discussed. The document concludes with a list of the components used and indicative suppliers, aiding in the replication of the module.

The complete documentation of the 3D Lidar front sensors module design is provided below.

- 3D Lidar front sensors documentation

A cherry picked selection of figures from the Agrofelis 3D Lidar front sensors design and fabrication documentation, is presented by the following figure.

Figure 11: Agrofelis steering system design and fabrication figures highlights

Two Degrees of Freedom Rotating Implement Mount (RIM) Design and Fabrication

The two degrees of freedom rotating implement mount document outlines the construction of the Rotating Implement Mount (RIM), a crucial component positioned atop the Agrofelis robot. The RIM's primary function is to enable the use of various implements, such as the thermal fogger featured in the presentation video. The rotation is achieved through the use of a stepper motor that powers the rotation by turning a gear on a turntable, while elevation/depression is achieved with the use of a linear actuator leveraging the mount, thus granting the RIM a two degrees of freedom (2DF) capability for any implement mounted on it. This report covers the rationale behind the module, its schematics, source code files and details of the manufacturing process. The document concludes with a list of the components used and assorted with indicative suppliers, facilitating the replication of the module.

The complete documentation of the RIM module design, is provided below.

- Two degrees of freedom rotating implement mount documentation

A cherry picked selection of figures from the Agrofelis RIM design and fabrication documentation, is presented by the following figure.

Figure 12: Agrofelis two degrees of freedom rotating implement mount figures highlights

Agrofelis Remote Controller Design and Fabrication

The remote controller design and fabrication document presents the details of fabricating a baseline remote controller for actuating the wheels, steering, brakes and power functions of the Agrofelis robot. Emphasizing ergonomics, cost-effectiveness and the use of readily available components, a simple extendable design is presented, rapidly prototyping the minimum number of sensors and components needed for booting and controlling the mobility functions of the vehicle. The module is de-compiled using annotated design plans with crucial metrics and is re-compiled using photos captured during the fabrication process. The software source code running on the micro-controller is also presented, following approaches similar to those implemented in other Agrofelis modules. The document concludes with a list of components used and provides information on indicative suppliers, aiding in the replication of the module.

The complete documentation of the remote controller module, is provided below.

- Agrofelis remote controller design and fabrication documentation

A cherry picked selection of figures from the Agrofelis remote controller design and fabrication documentation, is presented by the following figure.

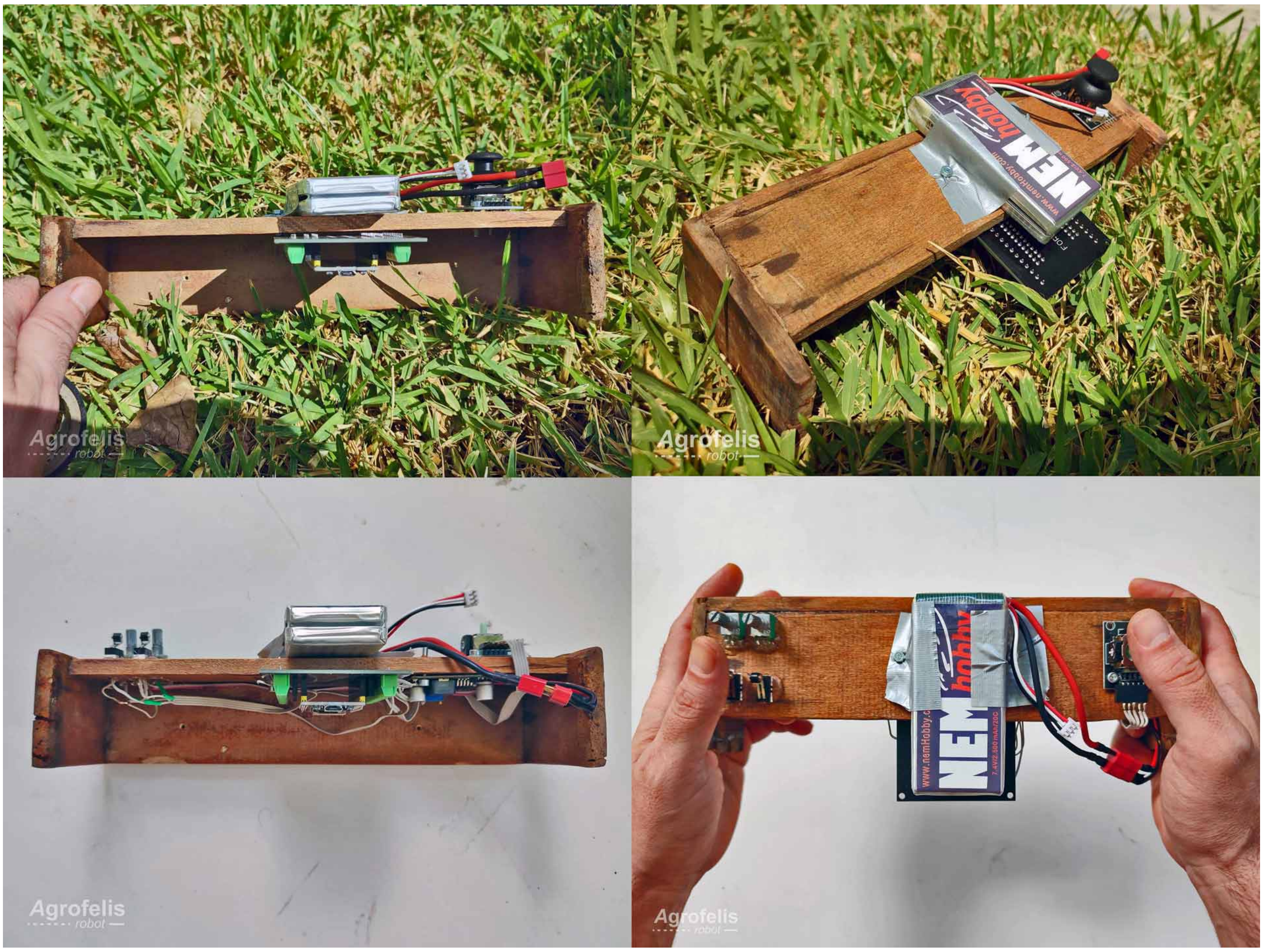

Figure 13: Agrofelis Remote Controller Design and Fabrication figures highlights

Infrastructure Provisioning, Computing Elements and Data Fusion

The infrastructure provisioning, computing elements and data fusion document presents the provisioning of the main computing elements for the Agrofelis robot and the initiation of its services. The peripheral elements established and attached to the local Agrofelis WiFi network and its USB hub are enumerated. In addition, the GPU component and the neural network accelerator tapping to the USBv3 interface of the Jetson Nano are presented. The Agrofelis Unificator Software, which connects all Agrofelis modules, is introduced along with its source code and features. The document also provides information on lightweight 3D printed structural elements that fit in the limited space available for the USB cables and secure the components and the USB hub in their compartment. The document concludes with a list of the components used and indicative suppliers, aiding the replication of the Agrofelis computing and networking systems.

The complete documentation of the infrastructure provisioning, computing elements and data fusion, is referenced below.

- Infrastructure provisioning, computing elements and data fusion documentation

A cherry picked selection of figures from the computing modules documentation, is compiled by the following figure.

Figure 14: Infrastructure provisioning, computing elements and data fusion figures highlights

Cost Estimation Overview

This sub-section outlines the indicative costs associated with constructing the Agrofelis robot. These figures are derived from estimated costs per item discussed in the relevant *indicative suppliers section* within each of the aforementioned documents, encompassing a diverse array of components crucial to the robot's assembly. It is important to note that the presented cost estimation incorporates applicable taxes. However, it is crucial to acknowledge that this estimation serves as a preliminary assessment and is subject to potential variations.

The values provided here are based on information gathered from indicative suppliers and are intended to provide a rough estimate of the project's financial requirements. In this estimation, we have focused solely on the intrinsic value of each component and have excluded supplementary expenses such as transportation, customs clearance, and unforeseen charges. These figures are the initial step in budget assessment and lay the foundation for more detailed financial planning.

The table showcased below provides a breakdown of the necessary construction components along with their associated indicative costs, enhancing comprehension for informed decision-making and budget formulation.

Construction Component	Sub-Total (€)
Chassis Frame	155.47
Wheels	575.20
Wheel Forks	53.30
Power System	1,509.28
Protective Covers	82.53
Steering System	132.88
Motors Hub Driver A	89.33
Motors Hub Driver B	89.33
3D Lidar Sensors	158.82
Rotating Implement Mount	322.58
Remote Controller	65.52
Computing and Network Components	485.34
Total Cost	**3,729.58**

Detail breakdowns of cost estimations for the manufacturing of each component can be accessed via the hyperlinked components, offering the ability to explore comprehensive analyses of the cost determination for each individual component.

Consequently the total manufacturing cost for the Agrofelis robot is **3,729.58** euros, excluding shipping and assembly costs.

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- Christos Spetseris, from QOOP Metalworks for his design and 3D CAD training support.
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- Luka Drašak, for his photographic and video recording support during the field tests.
- The crew of the Myrtia Fire Station in Southern Greece for sharing fire fighting tactics.
- Hellas Digital, for their excitement and discussions about the robotic vehicle.

Contact us

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Hack a day project page: https://hackaday.io/project/192733-agrofelis-robot

Figure 15: Agrofelis Robot Logo

Modules documentation

The components documentation have been rendered using Latex into PDF and have been appended into this unifying book, forming the Agrofelis documentation handbook.

Agrofelis Chassis Frame Design and Fabrication

Documentation

Agrofelis

Document created on 2023-10-09 03:38:42

Abstract

The current document focuses on the manufacturing details of the vehicle's frame. The frame houses and protects the 8kw power module with its LiFePO4 batteries, the electronics, the sensors and actuators of the unmanned vehicle. The frame was implemented using a total of 7.35 meters of 20X20 mm regular square iron bars, it establishes key placeholders for mounting the detachable wheels, the protective covers and via its grid-like attachment points enables mounting anticipated tools, as well as future ones. The primary design considerations were footprint minimization, battery compartment protection, chassis rigidity, and ease of manufacture utilizing low-budget tools and readily available materials. The documentation presents the frame fabrication by decomposing it into its individual elements and fabrication steps.

Contents

Introduction

The cross like symmetric chassis frame of the vehicle can be decomposed into identical bottom and top parts, a middle part contributing to the chassis height, front and back wheel mounting points, a fixed protective cover for the batteries, and a grid-like array of mounting sockets.

The following figure illustrates the schematics of the chassis from multiple view points.

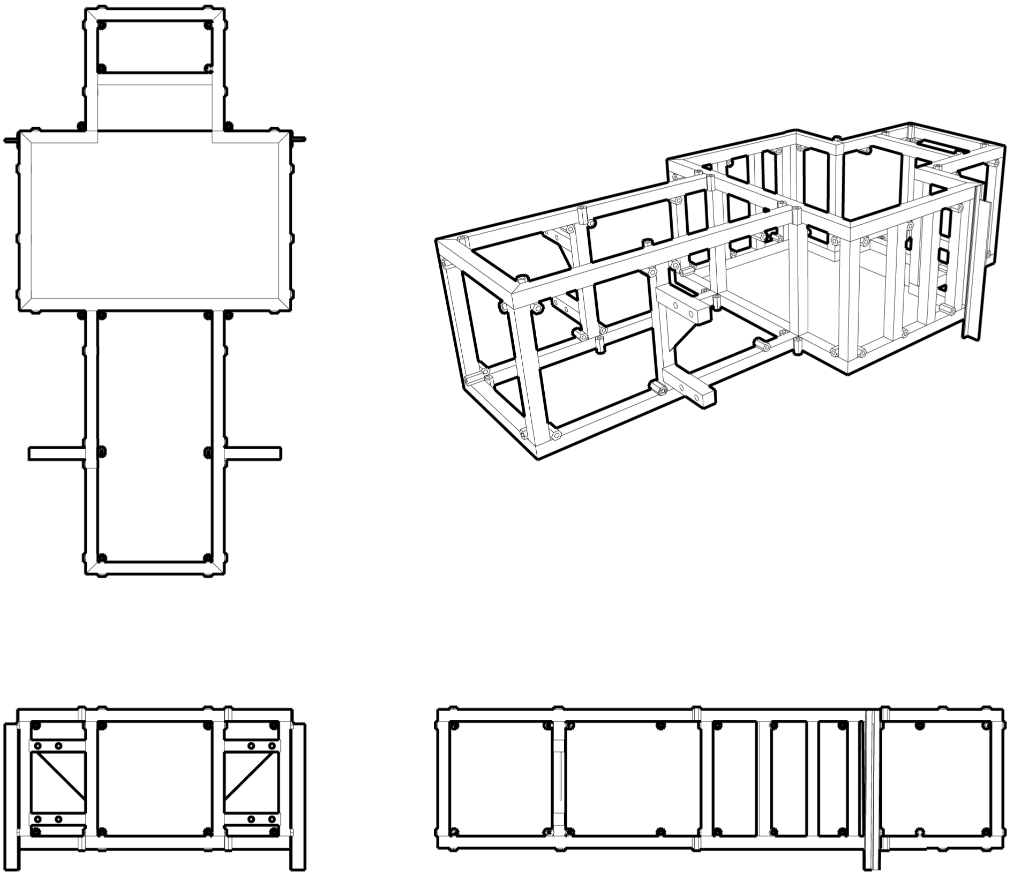

Figure 1: Views of the frame

Crucial dimensions of the frame and its components are annotated in the following diagram.

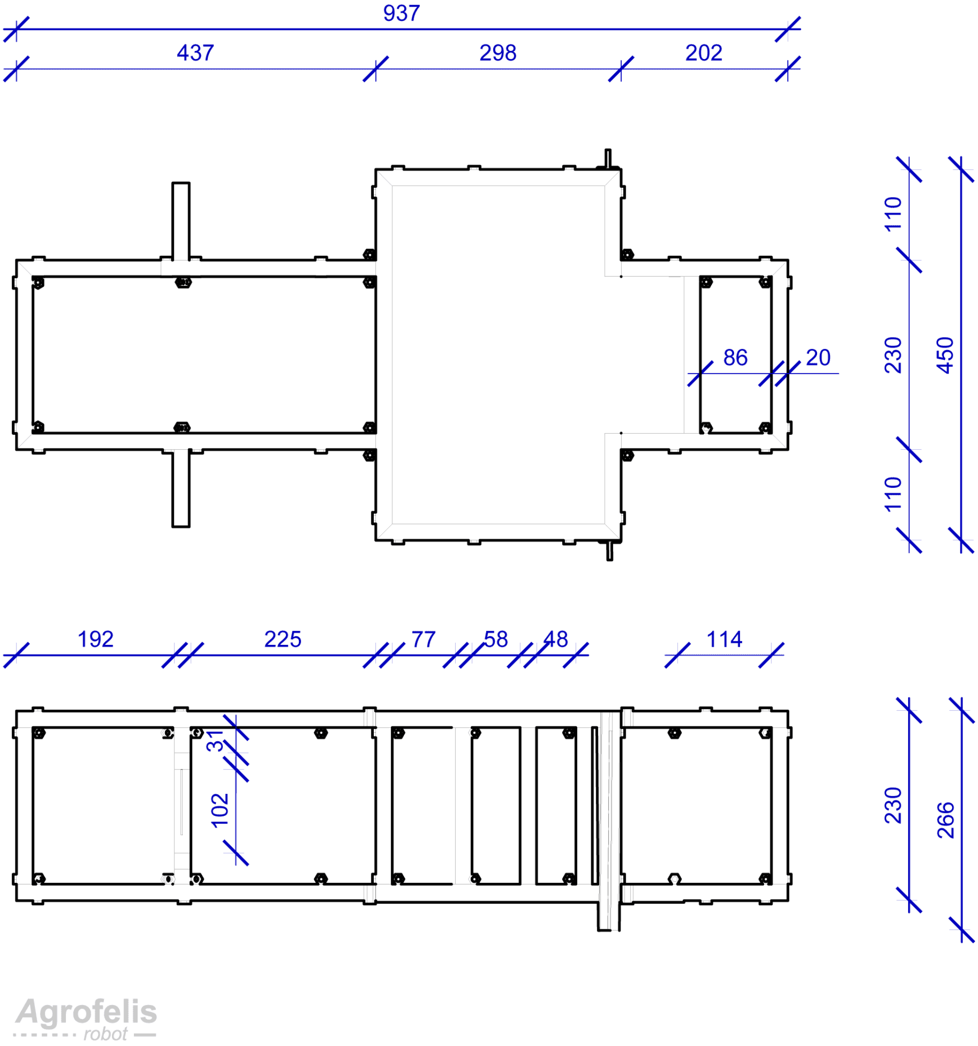

Figure 2: Key dimensions of the frame

The frame with its components arranged in an exploded view, is presented below.

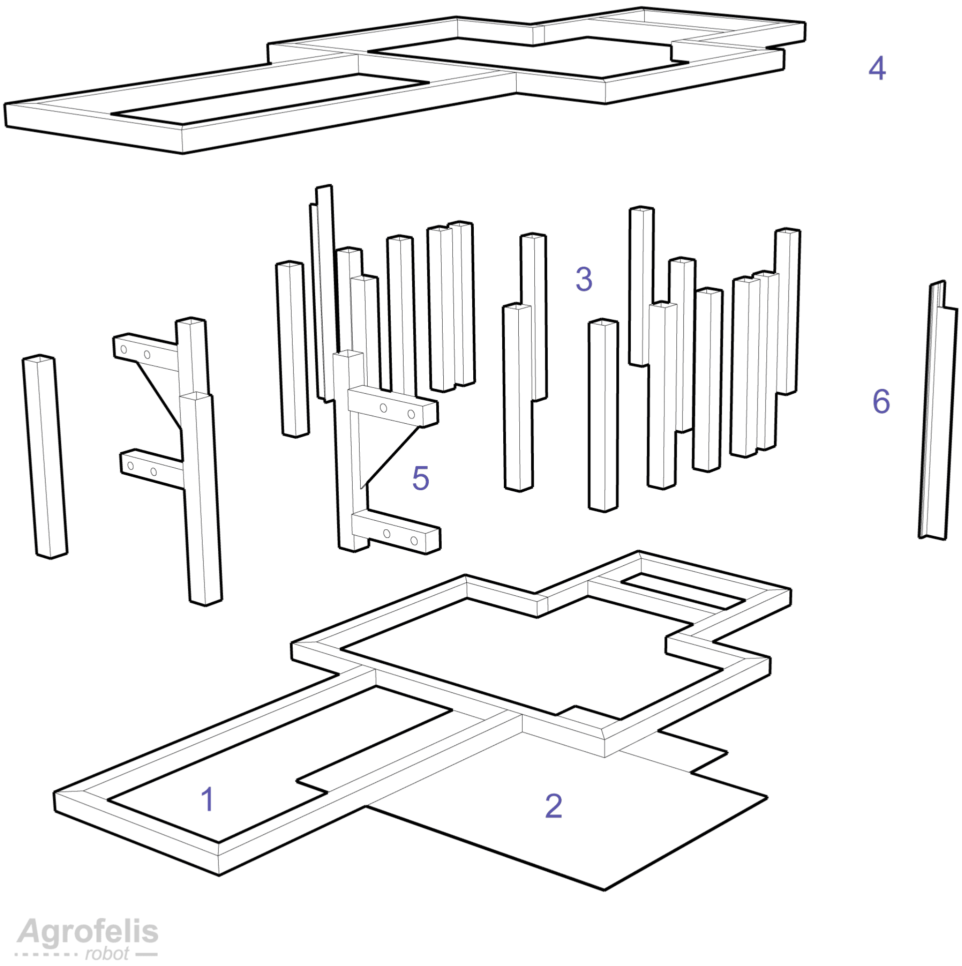

Figure 3: Exploded components of the frame

In the preceding diagram, numerical annotations are used to indicate various subpars of the frame, each labeled as follows:

1. The bottom part
2. The bottom batteries cover part
3. The middle bars
4. The top part
5. The back wheel mounting points part
6. The front wheel mounting points part

Stepwise Frame Fabrication

This section delves into the systematic fabrication of the chassis, which unfolds across seven distinct steps. In addition, for each step, we provide accompanying images to aid comprehension and ease of reference.

Step 01

The first part of the chassis fabrication is the bottom part, which is clearly illustrated by the following projection diagram.

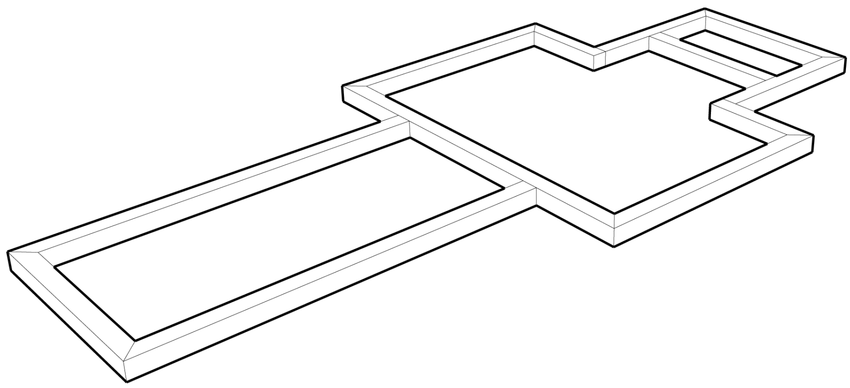

Figure 4: Manufacturing the frame step 1

Step 02

In the second step, in the bottom part of the frame, a 3 mm thick iron sheet following the battery compartment silhouette is welded, securing the 8kw LiFePO4 batteries from external forces, as illustrated by the following diagram.

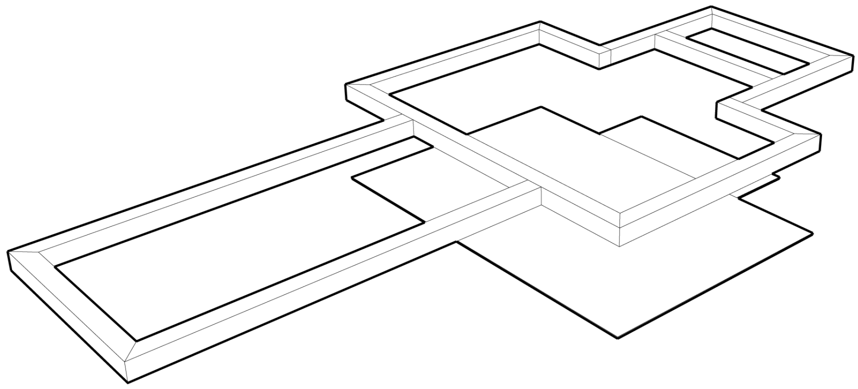

Figure 5: Manufacturing the frame step 2, battery bottom protection cover

Step 03

In the third step of the fabrication, the top part is being implemented. This part, in conjunction with the already constructed bottom part, is showcased in the diagram below.

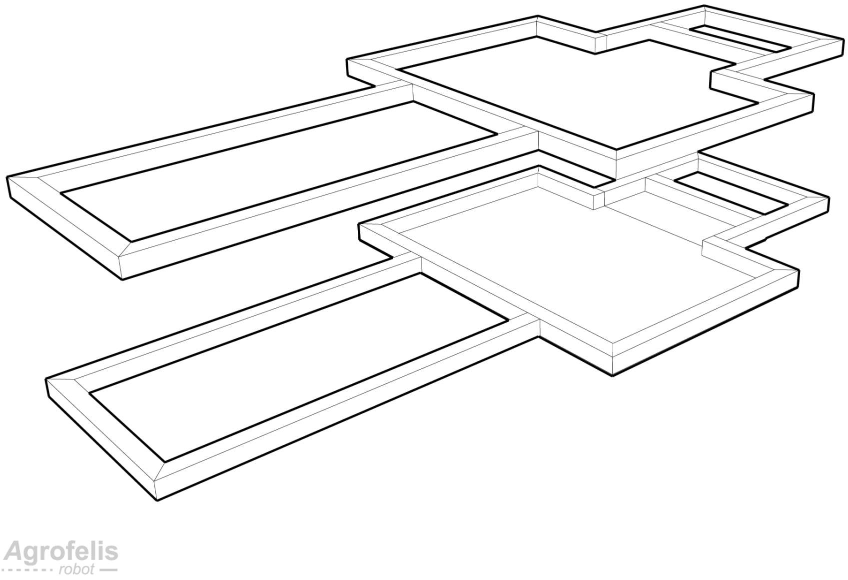

Figure 6: Manufacturing the frame step 3, bottom and top parts

The bottom and top part of the frame as fabricated are snapshot-ed, by the following images.

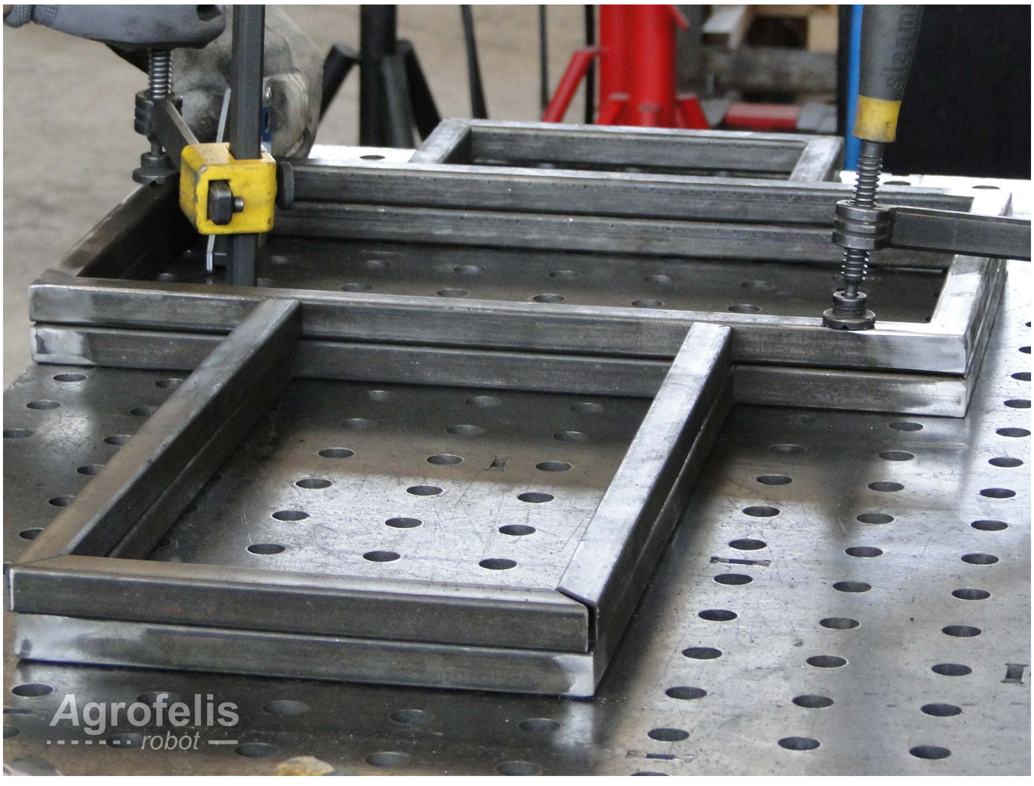

Figure 7: Manufacturing the frame step 3, fabricated bottom and top parts aligned

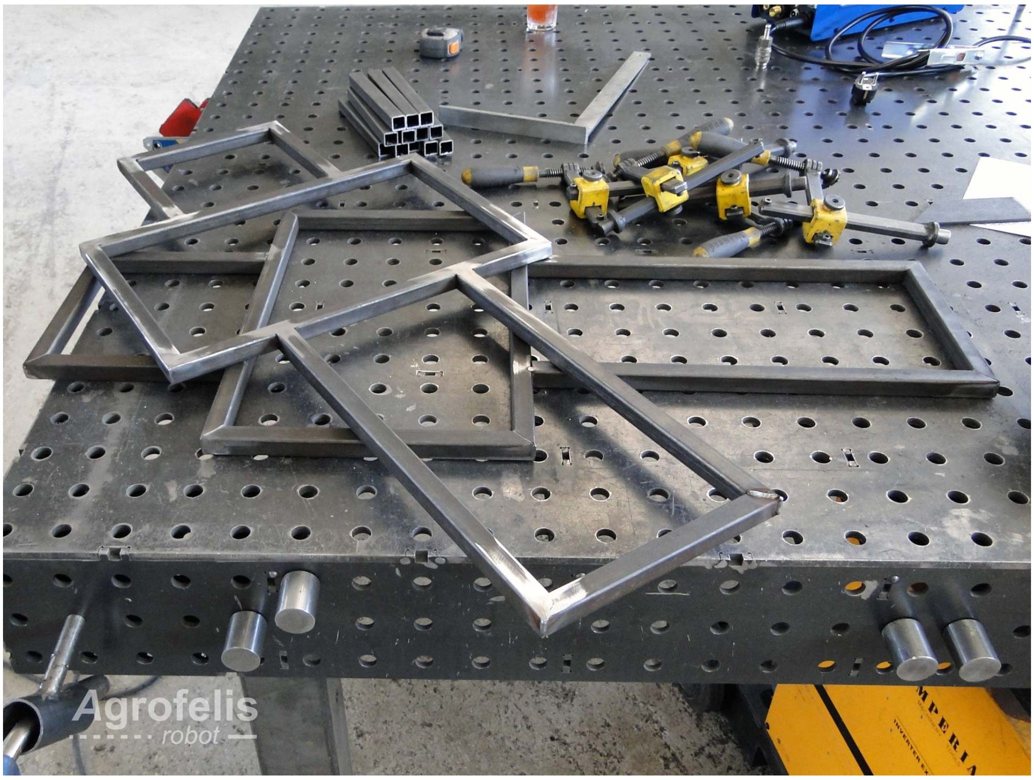

Figure 8: Manufacturing the frame step 3, fabricated bottom and top parts

Step 04

In the fourth step of the fabrication, the middle bars are MIG welded, connecting the top and bottom parts implemented in the previous steps, as shown in the image below.

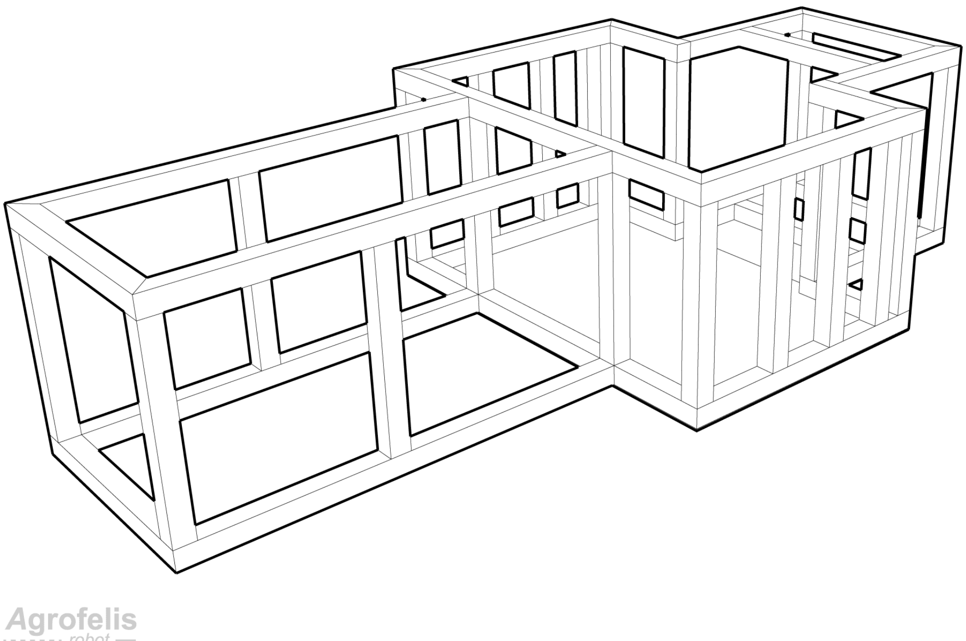

Figure 9: Manufacturing the frame step 4, middle bars

The following images showcase the fabricated top, bottom and middle parts of the chassis.

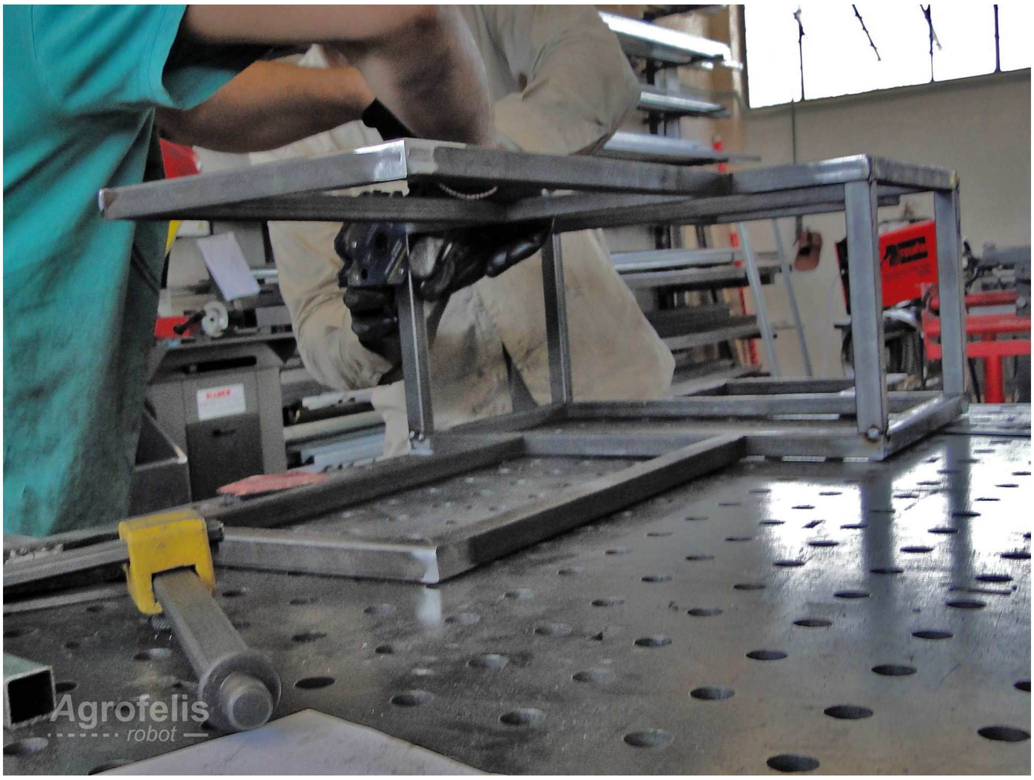

Figure 10: Manufacturing the frame step 4, fabricating the middle bars in progress

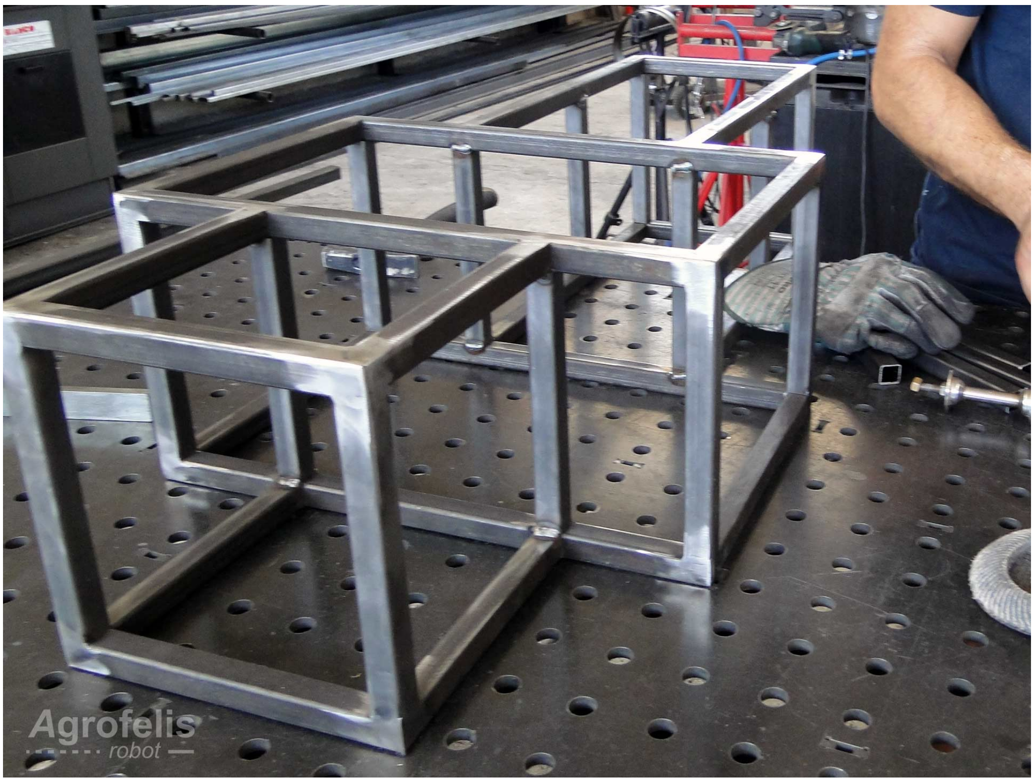

Figure 11: Manufacturing the frame step 4, fabricating the middle bars, completed

Step 05

Proceeding to the fifth step of the fabrication, the back wheel attachment points are being fabricated, as depicted in the succeeding illustration. The back wheel attachment points, enable to dismantle the related modules or to interchange the steering wheels according the the scope of the problem.

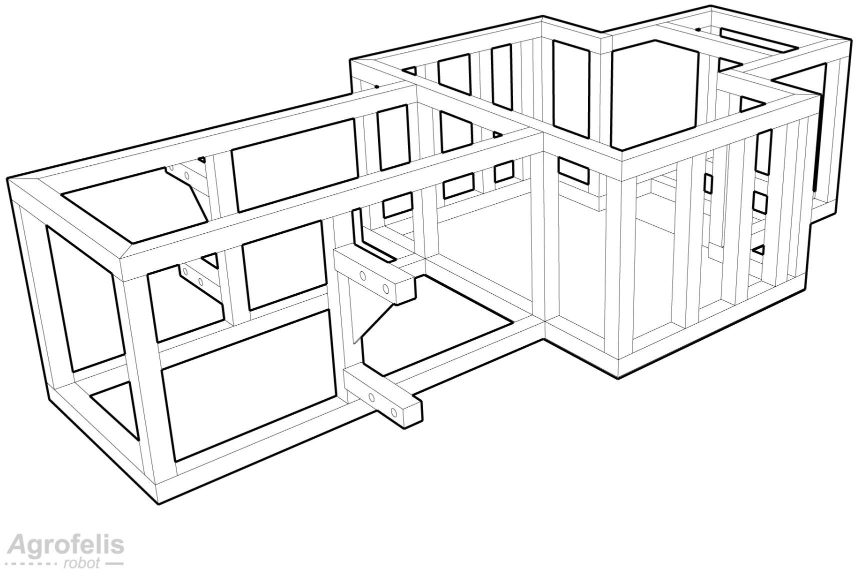

Figure 12: Manufacturing the frame step 5, back wheels attachment

Further insight into the manufactured part can be seen in the following image.

Figure 13: Manufacturing the frame step 5, back wheels attachment fabricated

Note: Although not crucial, these vertical bars can be offset-ed by 30 mm, something that is performed by the prototype frame using some additional drilled bars and washers, meticulously documented in the dedicated document presenting the steering wheels module.

Step 06

In the sixth step of the chassis fabrication, the front wheel attachments, using regular T-shaped iron bars of 25 mm width by 25 mm height, are welded onto the corner bars, allowing to interchange easily the front wheels of the robot and to support future wheel design variations based on the problem targeting.

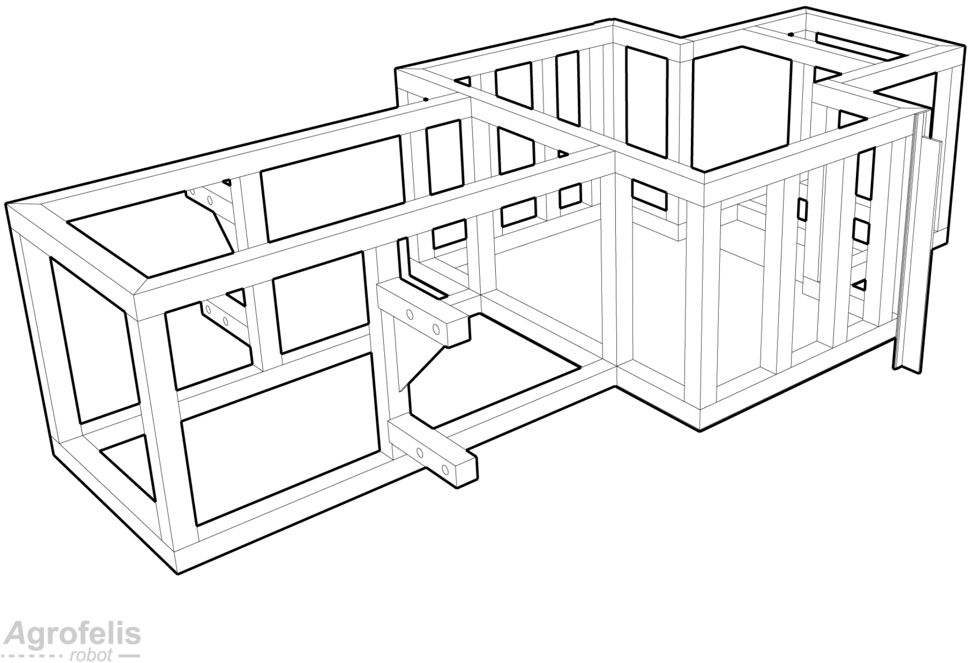

Figure 14: Manufacturing the frame step 6, Front wheels attachment

Step 07

Concluding with the seventh step of the chassis fabrication, 76 nuts are welded into every corner formed by the iron bars. These nuts serve dual purposes, allowing to mount the protecting covers of the frame and establishing multiple mounting points for tools and extensions of the Agrofelis Robot. The arrangement of grid-like mounting socket locations in the fabricated chassis is depicted in the following image.

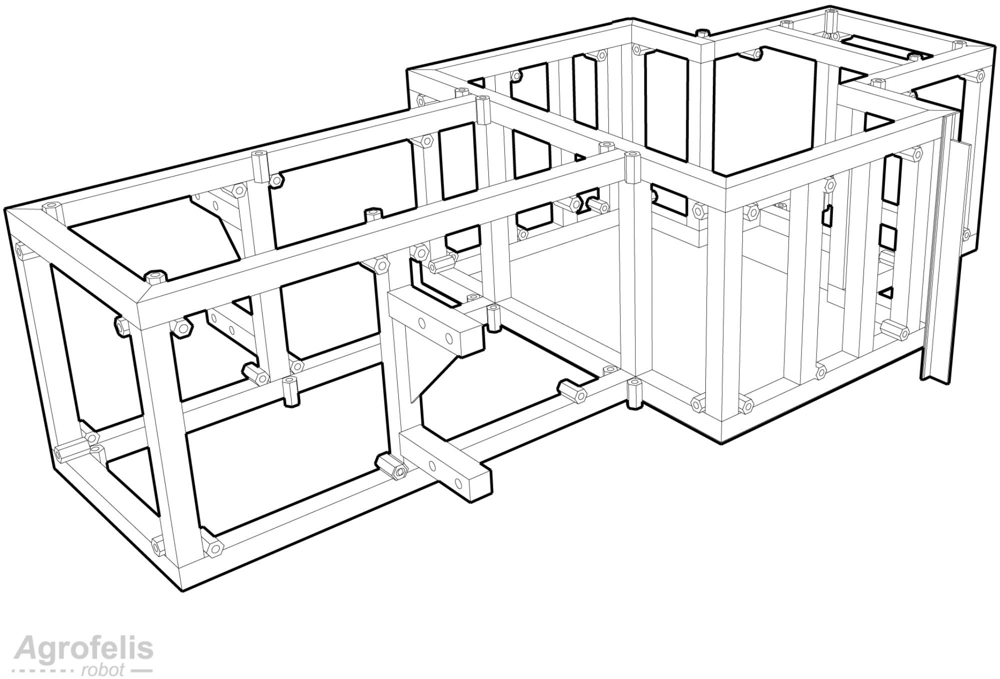

Figure 15: Manufacturing the frame step 7, Nuts forming multiple attach points

The subsequent figure showcases two perspectives of the painted fabricated frame .

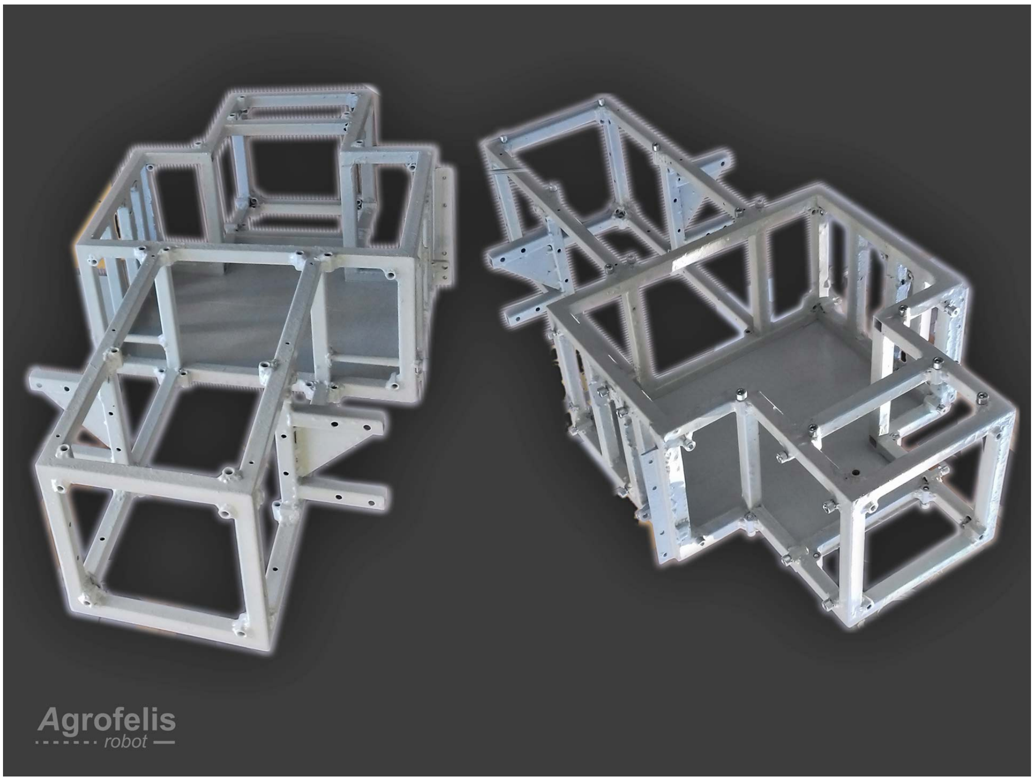

Figure 16: Views of the fabricated frame

Finalization Steps

As with all metallic parts of the Agrofelis robot, the frame is being coated with a two-layer primer application, followed by a double coating of oil paint. Additionally, a 5 mm compressible adhesive foam is glued to the external surfaces of the frame. This measure ensures almost air-tight protection when the covers are attached, effectively safeguarding internal components against dust and water.

Chassis Components and Indicative Suppliers

The following table lists the individual components employed for manufacturing the Agrofelis chassis frame. The index table includes moreover the product URL, the indicative supplier, as well as the unit price total Amount.

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#1	6 meters black iron square bar 20mm X 20mm X 2mm	Square bar	QOOP Metalworks	2	7.00	14.00	Few meters remain from the batch that can utilised for others parts
#2	Black iron metal sheet 1000x2000x3mm	3mm metal sheet	QOOP Metalworks	1	73.85	73.85	A significant area of the product can be reused to fabricate other components
#3	1 meter black iron T bar 25 x 3	T bar	QOOP Metalworks	1	6.00	6.00	-
#4	100 pack nut connector M08X24mm	Nut M08X24mm	Droutsas	1	13.00	13.00	-
#5	Self-adhesive foam	Adhesive sealing foam	Egarbis	2	4.70	9.40	-
#6	750ml Vitex Metal Primer	Primer	Stereotiki	1	6.50	6.50	-
#7	Gray oil paint 0,375 kg	Metal paint	Vrontinos	1	5.60	5.60	-
#8	Brushes	Brush	Nova Ceramica	3	1.00	3.00	-
	White spirit	White spirit	Rigatos Shop	1	1.50	1.50	-
	Paper sheet	Paint paper	Xromagora	5	0.80	4.00	-
#9	100 pack Allen screws DIN 912 8.8 M 8 x 25	Screws M8X25	Sinter Hellas	1	18.62	18.62	-
Total						**155.47**	

The total cost to manufacture the Agrofelis frame excluding shipping, cutting, welding and painting costs, sums to approximately **155** euros.

Summary

The development process, component details and essential dimensions for reproducing the Agrofelis chassis has been documented in a progressive manner. A photograph of the vehicle with some covers removed, exposing details of the end frame, is presented in the closing image below.

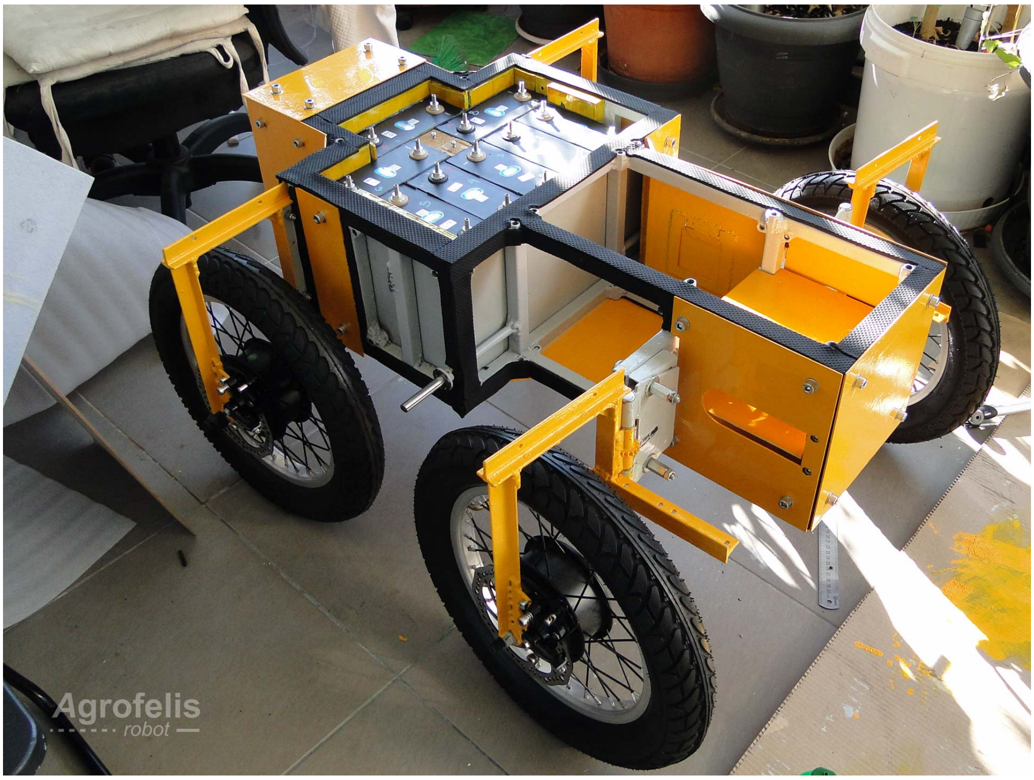

Figure 17: Close up view of the frame

End of document

Agrofelis Robot Wheels Fabrication

Documentation

Agrofelis

Document created on 2023-10-09 03:49:12

Abstract

This document presents a comprehensive overview of the manufacturing process behind the four-wheel drive (4WD) system of the Agrofelis robotic vehicle. It begins by detailing the specific requirements and then progresses to the completed fabricated solution. The design plans, compilation procedures, assistance assets and images taken throughout development are presented in a step-by-step manner. The sub-components composing four Agrofelis wheels are indexed with their unit prices and overall cost, along with references to indicative suppliers.

Contents

Introduction

Finding an elegant solution for the mobility requirements of a low speed robotic vehicle such as the Agrofelis robot proved to be a time-consuming procedure requiring extensive research and consideration.

After researching various solutions and vendors, for the uncommon case of low rpm, high torque, small footprint and low cost, we concluded that a solution composed of geared in-wheel motor hubs, equipped with hall sensors, providing at least 120 total Newton meter (NM), operable at 24v with less than 1000 watt total power consumption and ability to withstand 350 kilos of weight, as well as fit within a 16 inch wheel, would be the appropriate characteristics of the designed solution. In order to maximise traction, steering, and load distribution, a 4WD active system rather than a 2WD drive was deemed necessary. In the following sections the details of the active wheels, their components and the indicative sub-component suppliers are documented.

Agrofelis Wheels

The requirements study resulted in an optimal solution employing four geared in-wheel hub motors of 250 Watt (0.33 HP) and 38 NM of torque each, summing up to 152 NM of torque and 1 KW (1.32 HP) of power, meeting all field requirements set for the Agrofelis robot. The wheel is assembled from individual parts allowing to variate according to the problem focused on. In the following sections the particular composition evaluated and employed is presented.

The wheel with its motor, spokes, spoke lacing pattern and 16-inch rim are all photographed below.

Figure 1: Wheel knit overview

The wheel decomposed to its sub-components, is illustrated by the following figure.

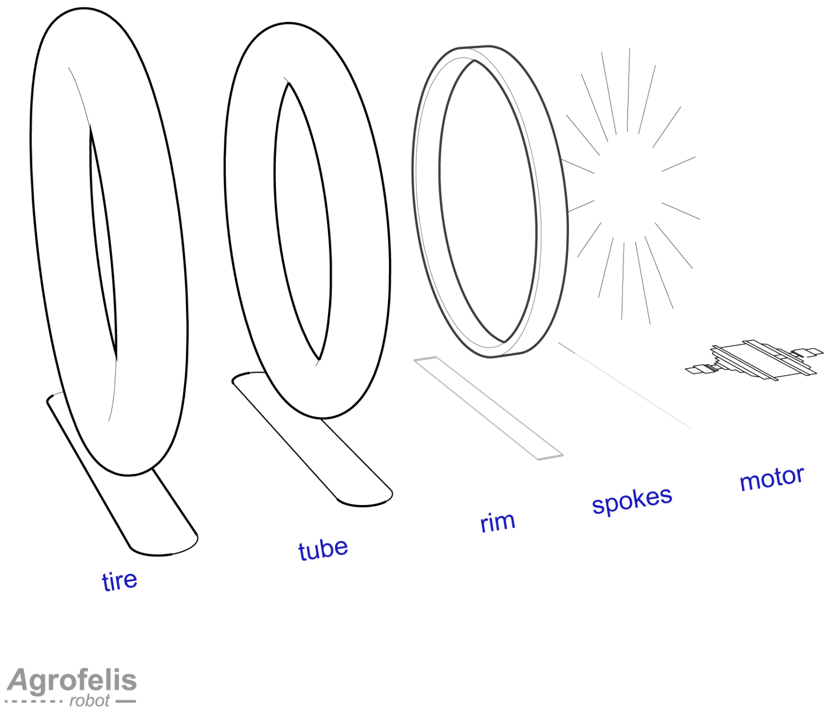

Figure 2: Wheel decomposition

Key dimensions of the individual components forming the prototyped wheel, are depicted in the following diagram.

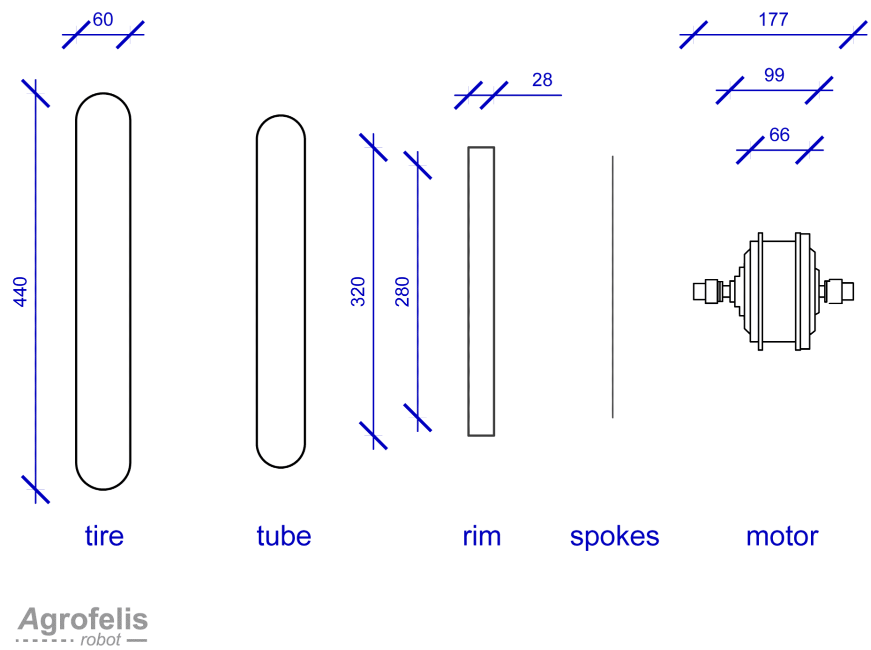

Figure 3: Wheel dimensions

The four wheels supporting the vehicle, are arranged in a nearly square layout, as shown in the diagram below.

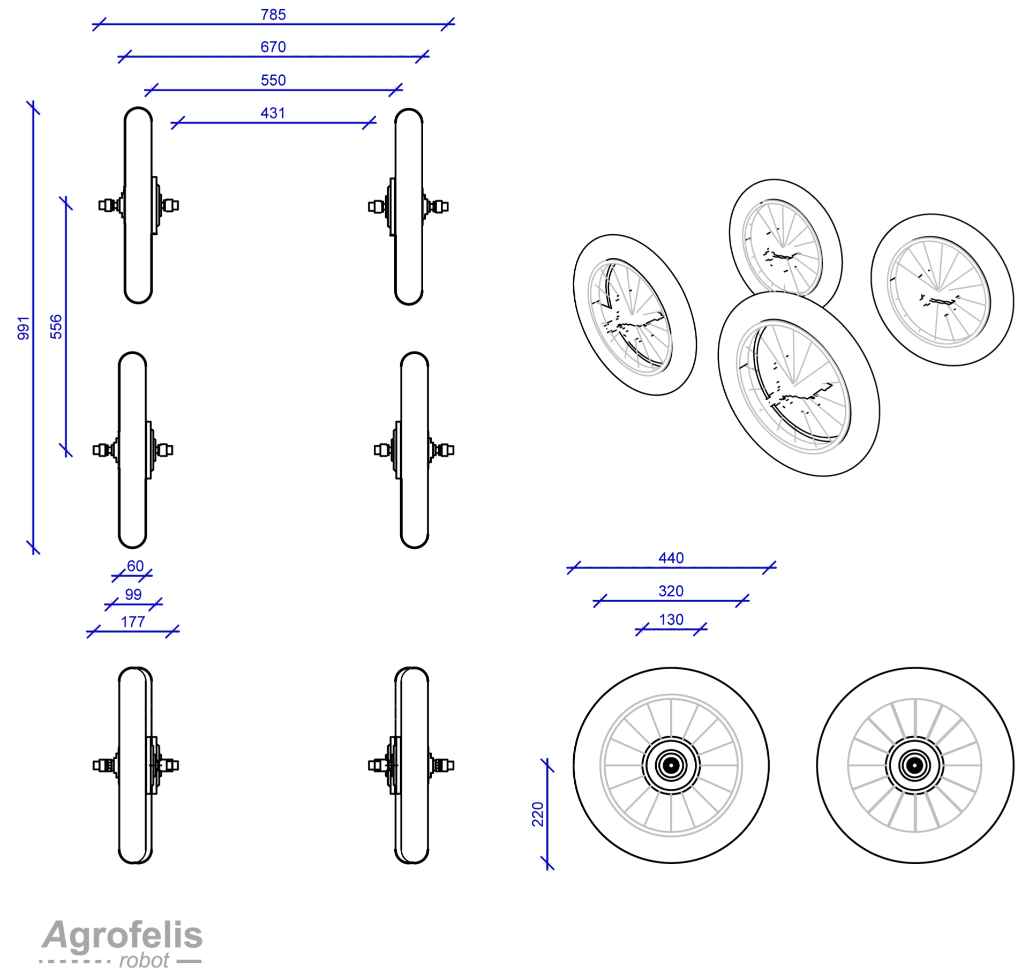

Figure 4: Wheels dimensions

Wheel Compilation

To optimize costs, and despite the fact that knitting the wheels by hand was quite laborious, the motor hubs were purchased without their rims so that they could reserve less volume, around 1/4, resulting in significantly lower shipping costs. Along with the motors, their respective motor drivers, the wheel spokes, the disc brakes and the fork brakes, were purchased from a foreign supplier. The 16-inch aluminium rims, the inner tubes and tires, were purchased from local suppliers.

The approach of purchasing the wheels unassembled provides the option of reducing or increasing the wheel size as long as the spokes length are adapted accordingly. The wheels spokes, which connect the motors to the rim, were knitted and aligned manually.

Four wheel modules were developed with disc brakes, inflatable tubes and fat tires to maximize the traction, for this kind of wheel size. The sub-components utilised are showcased in further detail in subsequent sections.

The following picture showcases the 250W, 24V in-wheel brush-less motor hub.

Figure 5: wheels motor

After communicating with various suppliers and evaluating the applicability of their products, the SR250D 250W brush-less hub motor from Suringmax was chosen due to its geared feature (1:4.4), waterproof IP54 IP grade, max torque power at 38 Nm, compatibility with a wide range of rim sizes including a 16 inch rim, and compatibility with a 24v system. The provider was also able to manufacture and provide custom spokes, according to the requested length such that they fit a 16-inch rim, something that played an important role for selecting them. Depending on the problem that the Agrofelis robot is intended to address, larger motors and/or rims/tires can be selected by following the equivalent procedure presented in this document.

The in-wheel motor hubs, were equipped with disc brakes, as shown in the image below.

Figure 6: wheels brake

Each of the motors supports 36 spokes, totaling 144 spokes for all four wheels, as shown below.

Figure 7: wheels spokes

A close-up view of the spokes along with their securing nuts (nipples), can be seen in the following photo.

Figure 8: wheels spokes

In order to match the number of spokes supported by the motors (36) and the customary number of spokes provided by low cost rims of this size (16), additional holes had to be annotated and drilled. A repeating pattern printable in regular size printer paper was designed. The PDF asset file encoding the associated pattern is referenced below.

- 36 holes drilling pattern for 16 inch rims

The pattern is printed four times and connected using transparent tape on the annotated remark line. Consequently, the pattern is cut and glued within the inner top surface of the rim. On the annotated positions, the rims are drilled to make up the appropriate connection points for the spokes.

The following figure showcases the printed pattern, depicting the spots where the related rim should be drilled.

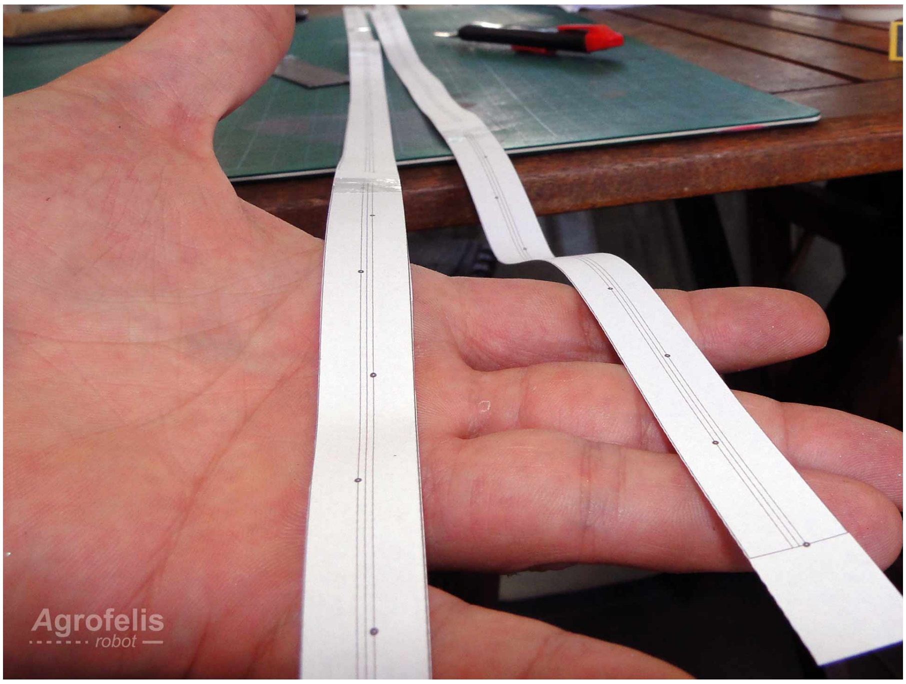

Figure 9: wheels pattern

A photo, showcasing the rim adaptation is provided.

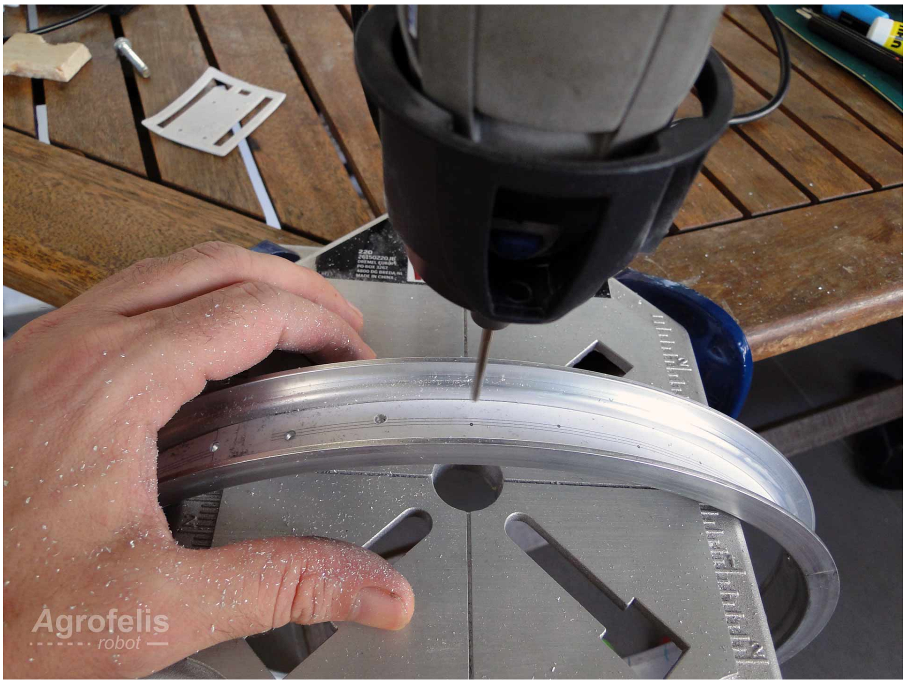

Figure 10: wheels drilling

The following photo compares the difference between the standard rim holes (16) and the new ones drilled (36).

Figure 11: wheels drill holes difference

The printed pattern moreover, hides the previous invalid holes, assisting the assembling procedure.

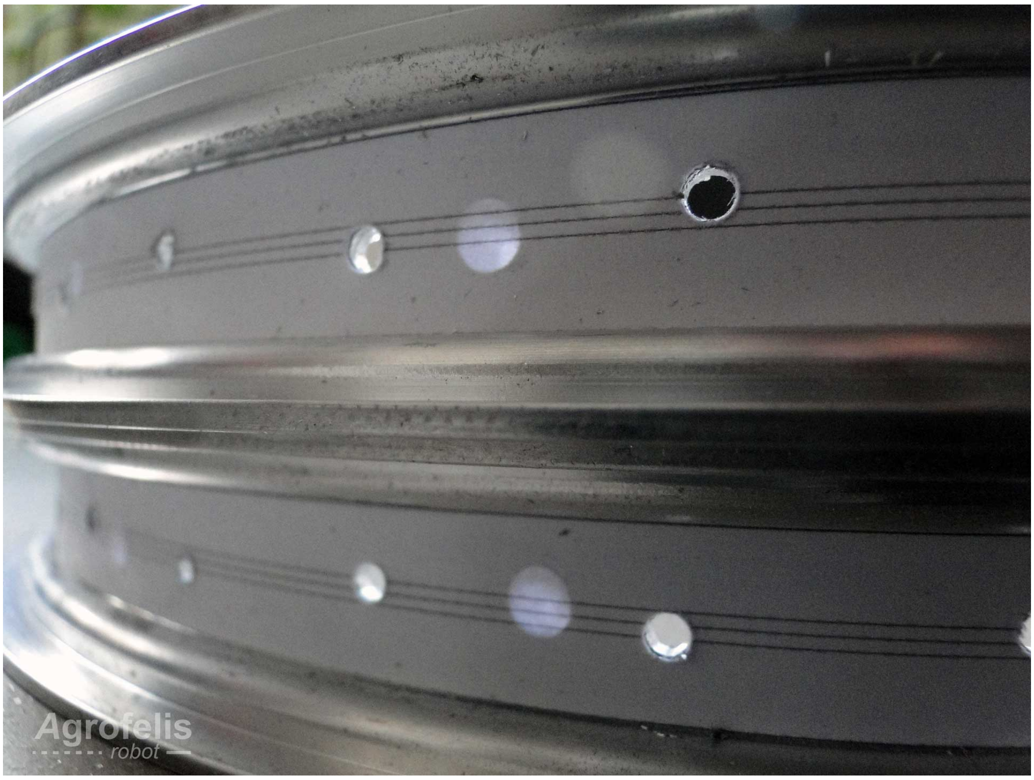

Figure 12: wheels selection

It should be noted that 16-inch wheels with 36 holes exist in the market at approximately twice the cost.

The image below displays the four assembled wheels without their tubes and tires.

Figure 13: wheels completed

The four fully completed wheels are captured in the following photograph.

Figure 14: wheels completed with tires

The motor hubs are connected to their motor drivers via a cable supplied with the motors. Consequently, the active wheels of the vehicle interface with the Agrofelis Motors hub driver modules, which enhances their functionality by enabling to digitally monitor and control the motors to perform precise and adaptive coordinated movements at near constant low RPM, regardless of ground slope.

Wheel Components and Indicative Suppliers

The following table lists the individual components used for manufacturing four Agrofelis wheels. The index table also includes the product URL, the indicative supplier, as well as the unit price total amount.

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)
#1	SR250D Suringmax Motor	Motor Hub	Suringmax	4	70.00	280.00
#2	36 spokes to fit the inner dimensions of the rims with inner diameter of 28 cm	-	Suringmax	4	3.00	12.00
#3	Disk brakes	-	Suringmax	4	5.00	20.00
#4	Motor drivers at 24v with forward and reverse driving and no display connection	Motor driver	Suringmax	4	15.00	60.00
#5	Viper tires 16 X 3.00	Fat tire	Podilatada	4	25.90	103.60
#6	SHINKO Tube 16X2.50/3.0	Tire tube	Podilatada	4	9.90	39.60
#7	16 inch aluminum rims	Rim	Podilatis	4	15.00	60.00
Total						**575.20**

Consequently, we observe that the total cost to manufacture four wheels, excluding shipping and assembly charges, is approximately **575** euros.

Summary

This document elucidated the design details for the Agrofelis active wheels. The manufacturing processes utilized for reproducing the particular prototype wheels, as well as implementing derivative variations, have been comprehensively documented. Approaches used to minimize shipping costs while also providing flexibility were highlighted. Images that chronicle the step-by-step procedures involved in reproducing the Agrofelis wheels, alongside detailed information for procuring the relevant subcomponents, were documented.

End of document

Agrofelis Robot Wheels Forks Design and Fabrication

Documentation

Agrofelis

Document created on 2023-10-09 03:57:09

Abstract

This document presents an overview of the fabrication process for the forks mounting the four wheels of the Agrofelis vehicle. These forks are intentionally designed to be detachable, so that the wheels could be removed or replaced with alternative ones. The forks are responsible for securing the active wheels of the vehicle, establishing active brakes actuated via servos, enabling steering and installing feedback rotating mechanisms. Two types of forks are being employed, those installed in the front and those installed in the back. The majority of fork designs are similar, with the only differentiating factor being the mounting mechanism aimed for fixed or steering purposes. The forks installed on the left and right sides are arranged in a mirrored fashion. The forks are constructed from regular iron T-shaped rods that have been cut and welded. Additional sub-components elaborated are the vehicle's fork mounting mechanisms and the parrot-like (drop out) elements securing the wheels via the motor's hub shaft. The design schematics, plasma cut patterns, as well as images of the fabrication progression are all documented. The document concludes by providing a list of indicative suppliers from whom the raw materials were acquired, further enriched with bill and material details.

Contents

Introduction

In order to minimize the footprint of the vehicle, to have a sturdier front structure where mechanisms could be mounted, to reduce the fabrication complexity and to cut manufacturing costs, the front wheels were designed with a fixed function in mind, while the back wheels were designed with a dynamic function implementing the steering of the vehicle. The forks utilized existing profile characteristics found in the bicycle industry and more specifically for the fork drop out and brake mounting points, so disk brakes could be employed. Fabrication of the forks and their mounting mechanisms involves regular 25 mm T-shaped rods, along with two plasma-cut components that are cut, drilled and MIG welded. All forks were designed so they are detachable in order to support future revisions or variations of the forks.

In the following sections, the Agrofelis forks are being decomposed into their sub-elements, showcasing their fabrication details.

Forks Arrangement

The following schematic illustrates the four wheel forks of the vehicle.

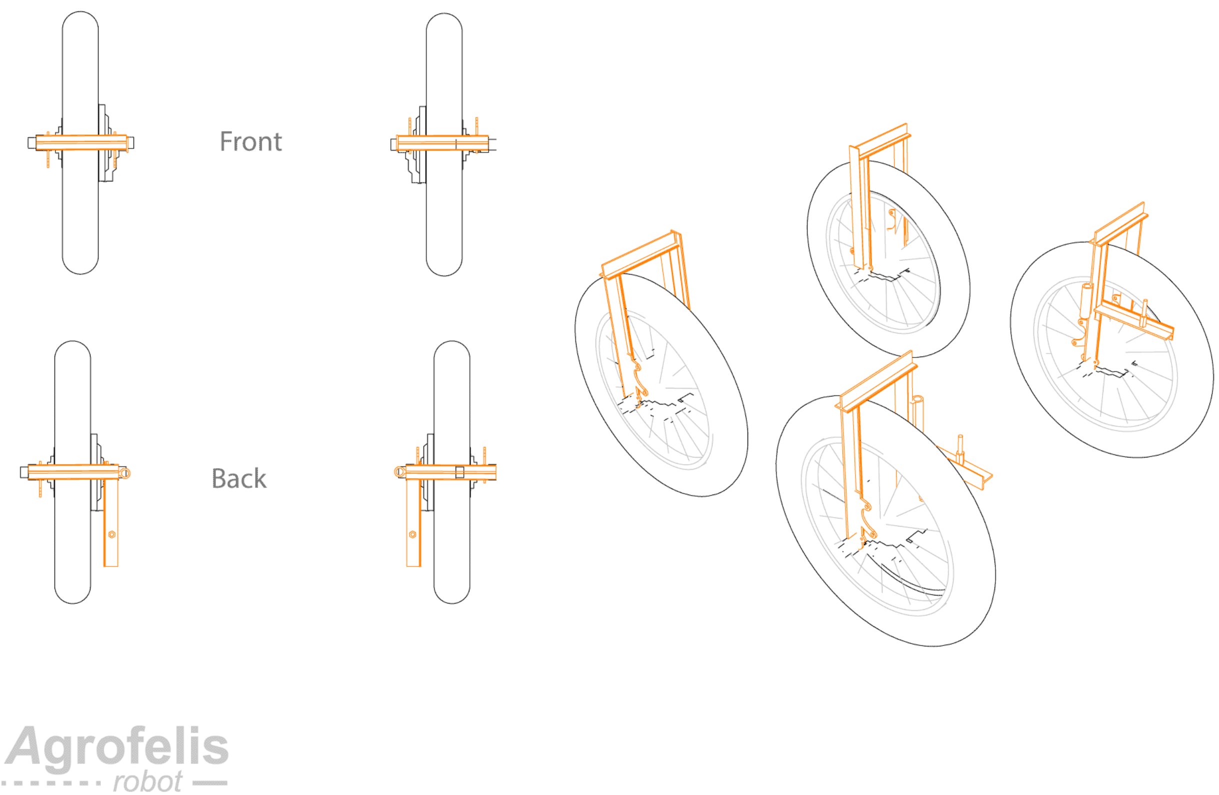

Figure 1: Forks and wheels

The following figure depicts the forks mirrored arrangement.

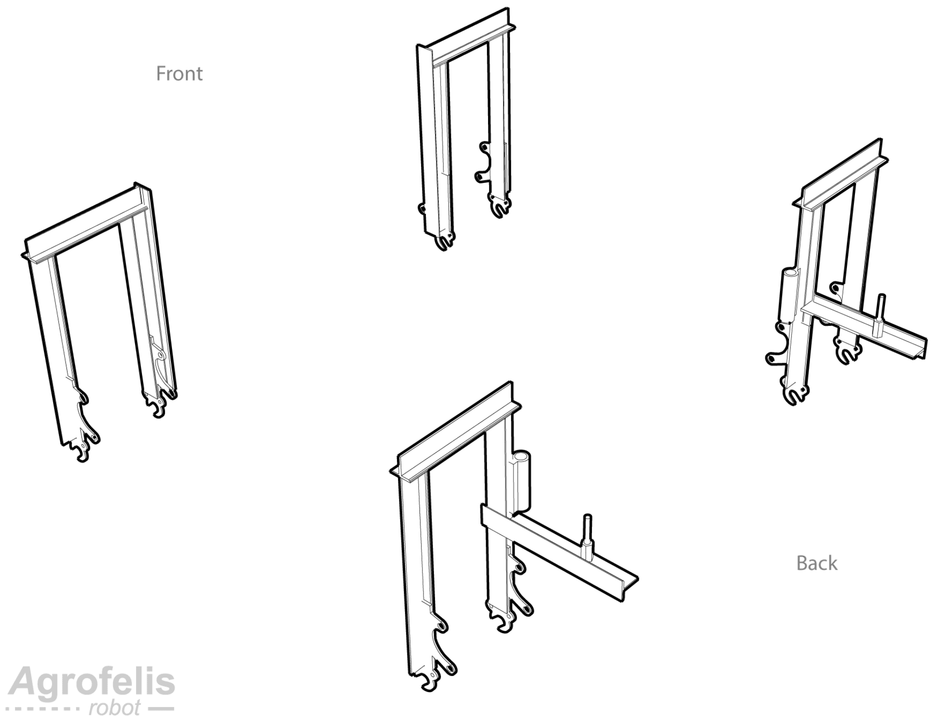

Figure 2: Forks projections

The image provided below highlights the two distinct types of forks, those located at the front and those positioned at the back of the vehicle.

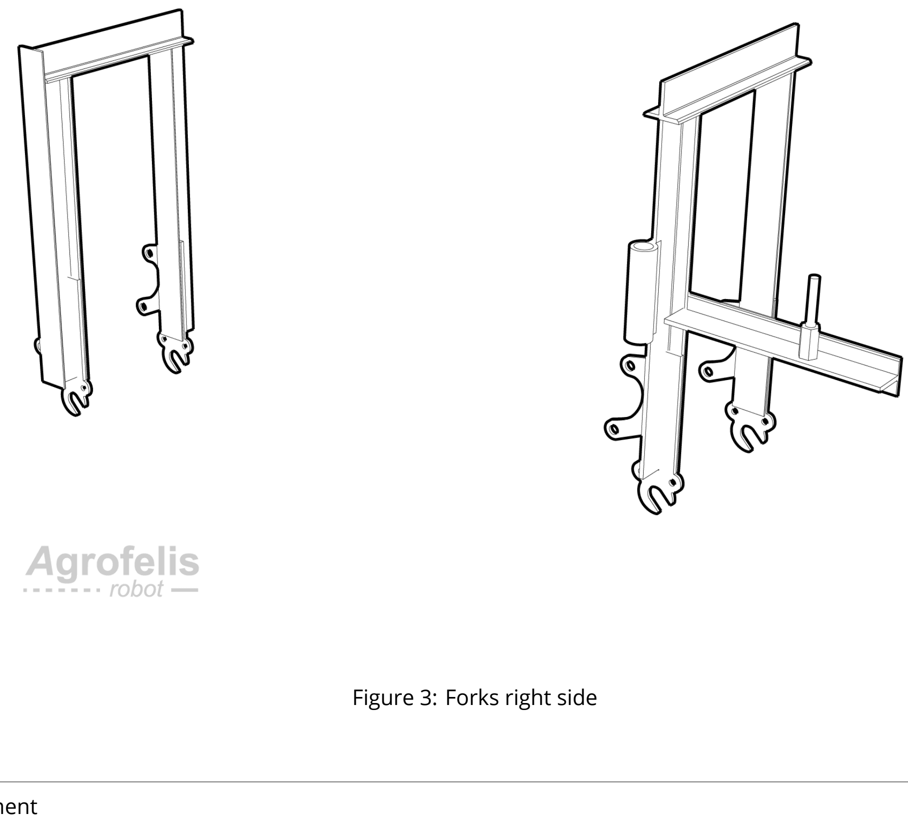

Figure 3: Forks right side

Front Forks

All fours forks share a common structure, differentiating only at the final fabrication stage based on their intended usage. The diagram below encodes the profile characteristics and dimensions of a front fork.

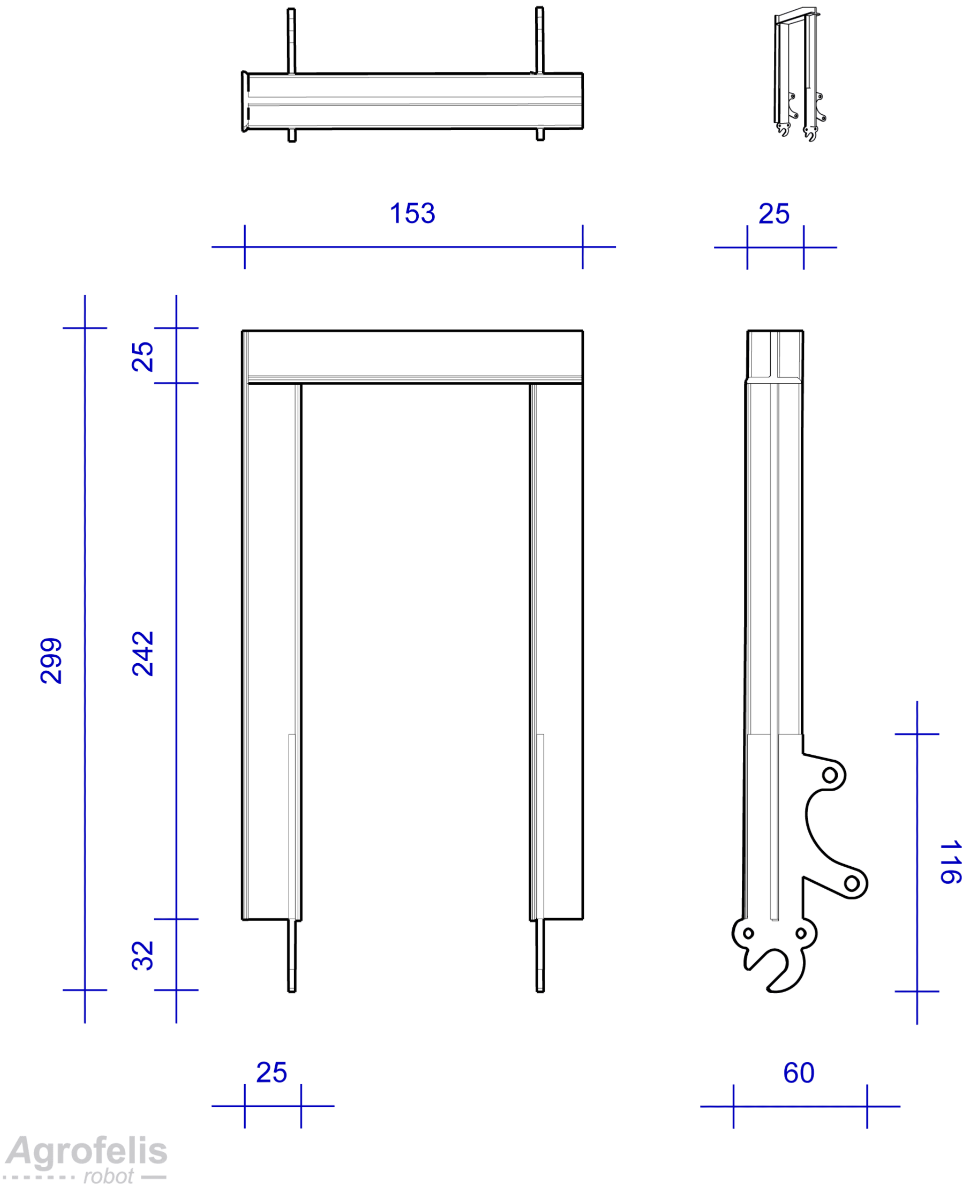

Figure 4: Front fork dimensions

The front fork mounting mechanism is also fabricated using a T-shaped rod, with its top part trimmed to create a socket for the fork's placement. The mounting mechanism is welded onto the vehicle's frame. Both the mounting mechanism and the fork are drilled and connected together using regular nuts and bolts. The mounting mechanism (A) of the front fork (B) is illustrated by the following figure.

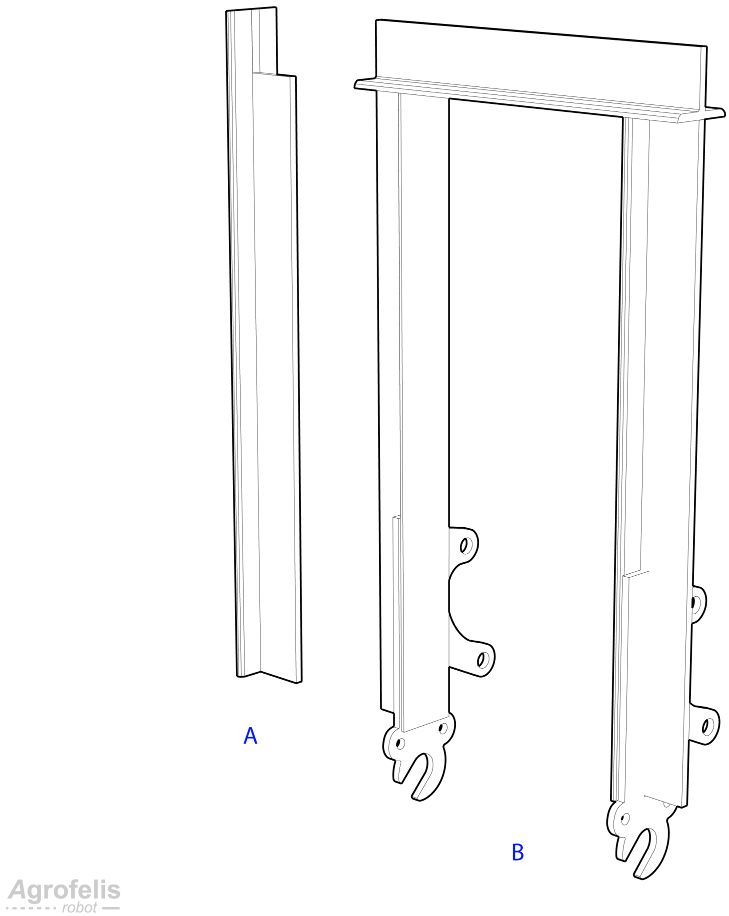

Figure 5: Front fork and mount

The front fork sub-parts are indexed by the following exploded view diagram.

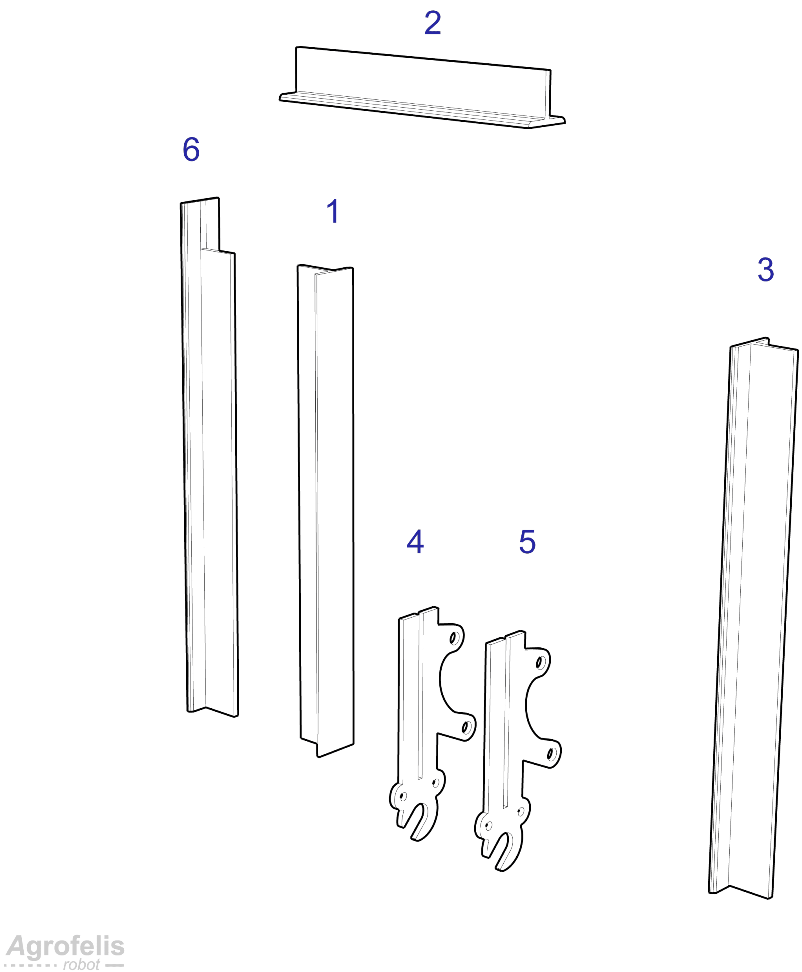

Figure 6: Front fork exploded view

The following part designed and fabricated, has a vertical socket allowing to slide within the T-shaped rod as seen by the following schematic.

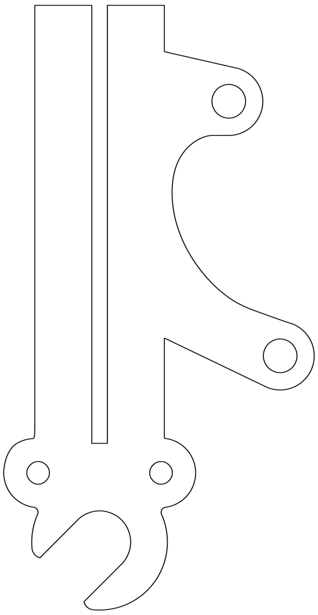

Figure 7: Fork drop out component plasma cut

Two of these elements are fabricated per fork and are welded in each of its bottom sides. The component accommodates for mounting the wheels, as well as for mounting the disk brakes mechanism. The NC files used to fabricate them are provided in the following directory in the open source repository.

- assets/forks_dropout

The following directory contains the scalable vector graphics design plan of the component, offset by 1 mm, accounting for the plasma torch diameter.

- forks_dropout_1mm_offset.svg

In addition, the NC (Numerical Control) instructions file sent to the CNC is available in the following file.

- forks_dropout_1mm_offset.nc

The SVG to NC conversion was accomplished by the Laser GRBL free laser engraving software and its outcome was transformed for a plasma cutter (z-axis actuation) using the open-source software developed for driving a custom DIY plasma cutter tailored for this specific purpose.

- https://github.com/meltoner/g-code-plasma-cutting

The fabricated plasma cut drop out component can be seen by the following image.

Figure 8: Fabricated drop out element

Back Forks

The back forks of the Agrofelis vehicle closely resemble to the front forks. They differentiate by welding the half part of a hinge on their side, as well as welding a lever where a liner actuator can push rotate the wheels at the desired degree. The back fork schematic and dimensions are encoded by the following diagram.

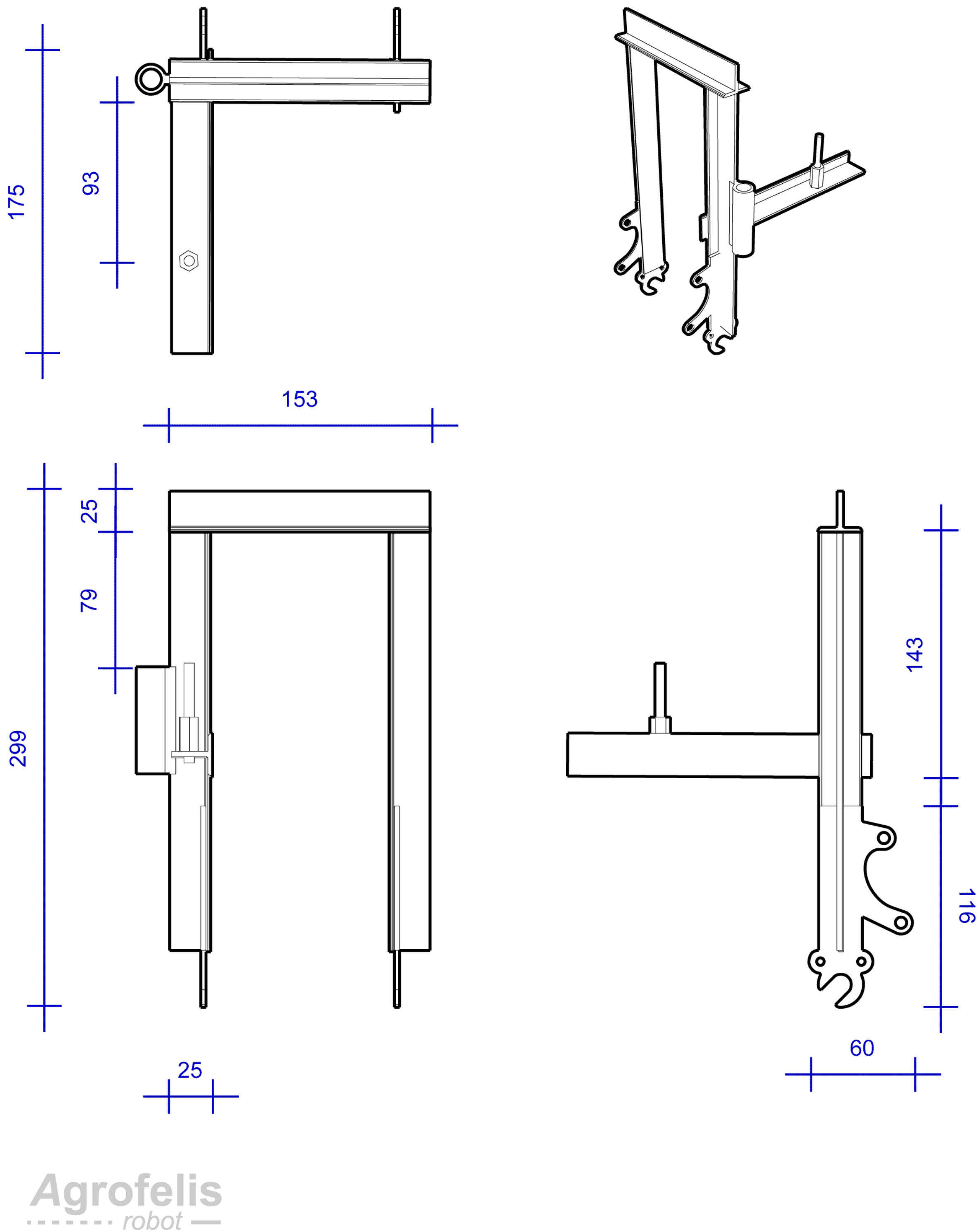

Figure 9: Back fork dimensions

The back fork sub-parts are indexed by the following exploded view diagram.

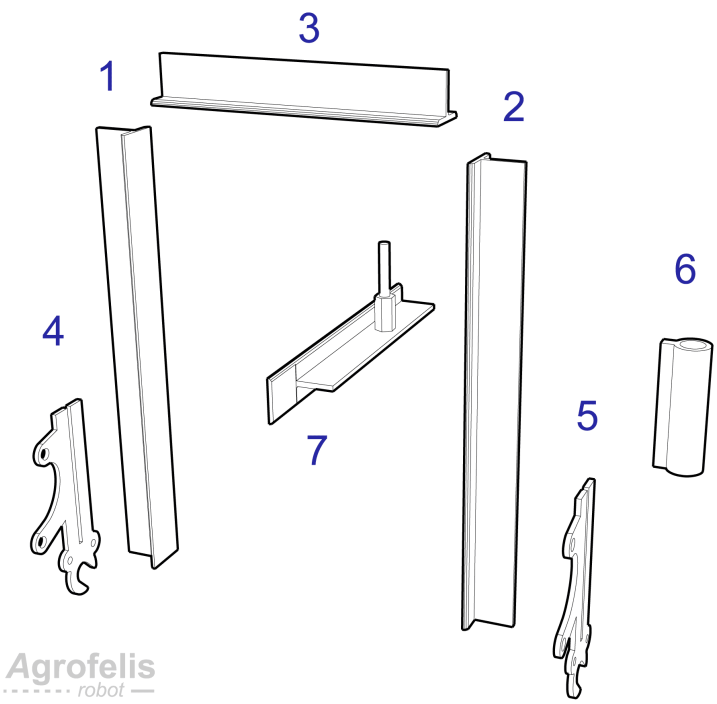

Figure 10: Back fork exploded view

A more detailed schematic of the related level element is encoded by the consequent image.

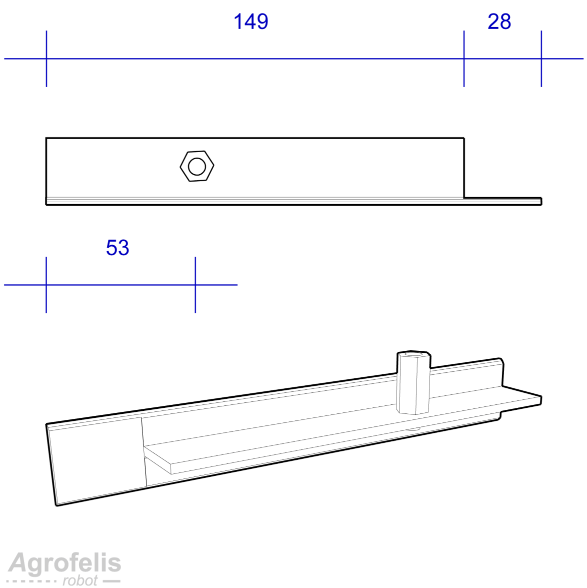

Figure 11: Back fork lever

Within the lever at the depicted distance a hole is drilled and an extended nut is installed via a bolt to accommodate the end of a linear actuator, rotating the wheel. Further details about this detail are covered in the Agrofelis steering design and fabrication document.

Sub-components of the forks laid out, ready to be welded have been photographed by the next image.

Figure 12: Multiple components of the forks

The back fork, is connected with the frame using a custom plasma cut part and a hinge. The half part of the hinge is welded into this component and the other half to the fork. The schematic of the custom cut part is presented by the following figure.

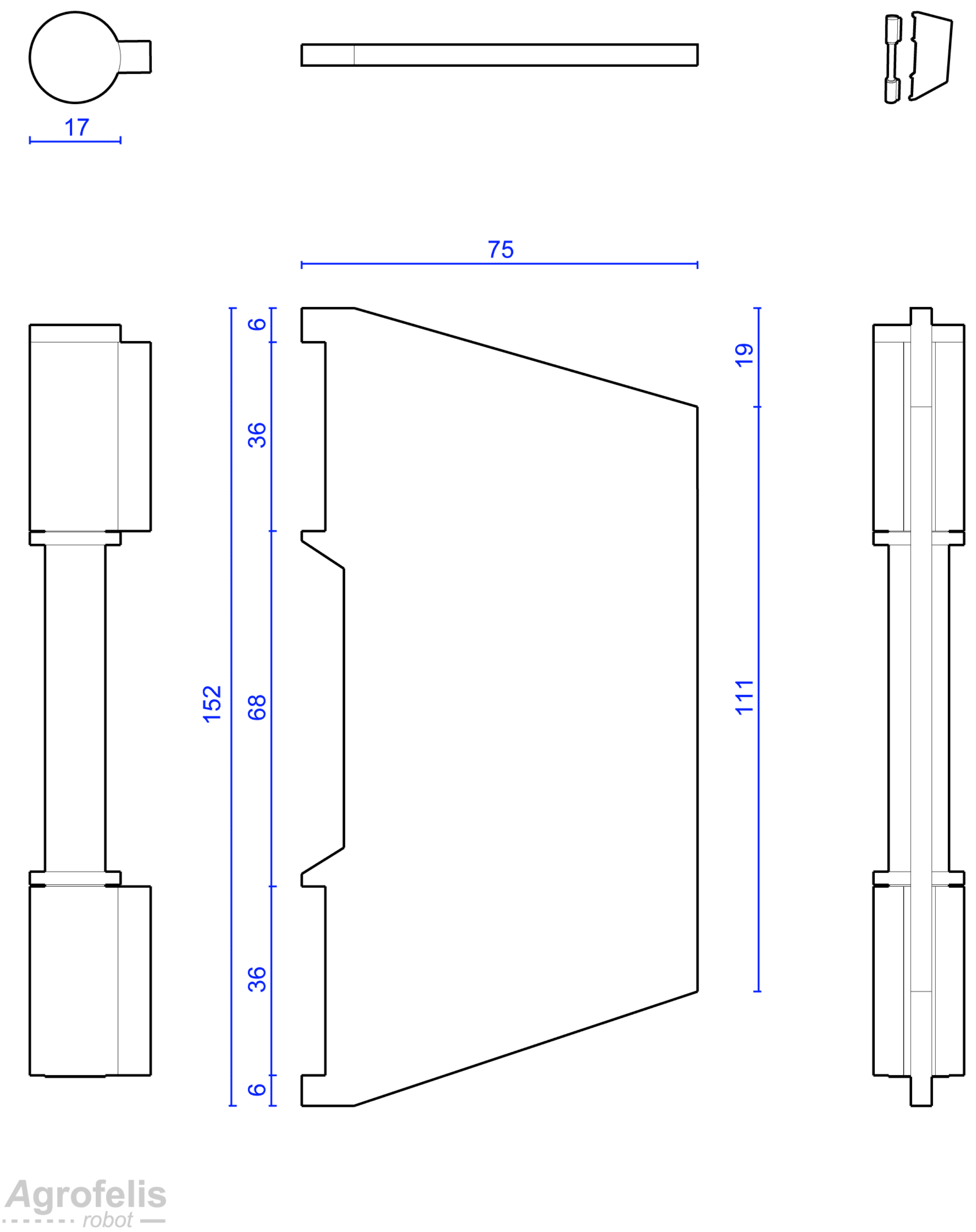

Figure 13: Back fork hinge-mount

Two of these elements are fabricated for the back forks and are drilled and connected to the frame using 12 mm bolt and nuts. The NC files used to fabricate them are provided in the following directory in the open source repository.

- assets/back_wheel_mount

The directory contains the scalable vector graphics design plan of the component, offset-ed by 1 mm, accounting for the plasma torch diameter.

- back_wheel_mount.svg

In addition, the NC (Numerical Control) instructions file sent to the CNC are provided by the following file.

- back_wheel_mount.nc

The SVG to NC conversion process was carried out using the Laser GRBL free laser engraving software and its outcome was converted for a plasma cutter (with z-axis actuation) using open-source software specifically developed to steer a custom DIY plasma cutter designed for this precise application.

- https://github.com/meltoner/g-code-plasma-cutting

The fabricated mounting mechanism as plasma cut and welded with the first half part of the hinge is captured by the following photo.

Figure 14: Hinge mount fabricated view a

A detailed view of the fork just prior to welding the second part of the hinge is depicted in the following photo.

Figure 15: Hinge mount fabricated view b

The steerable fork, successfully mounted onto the vehicle, is showcased in the ensuing photo.

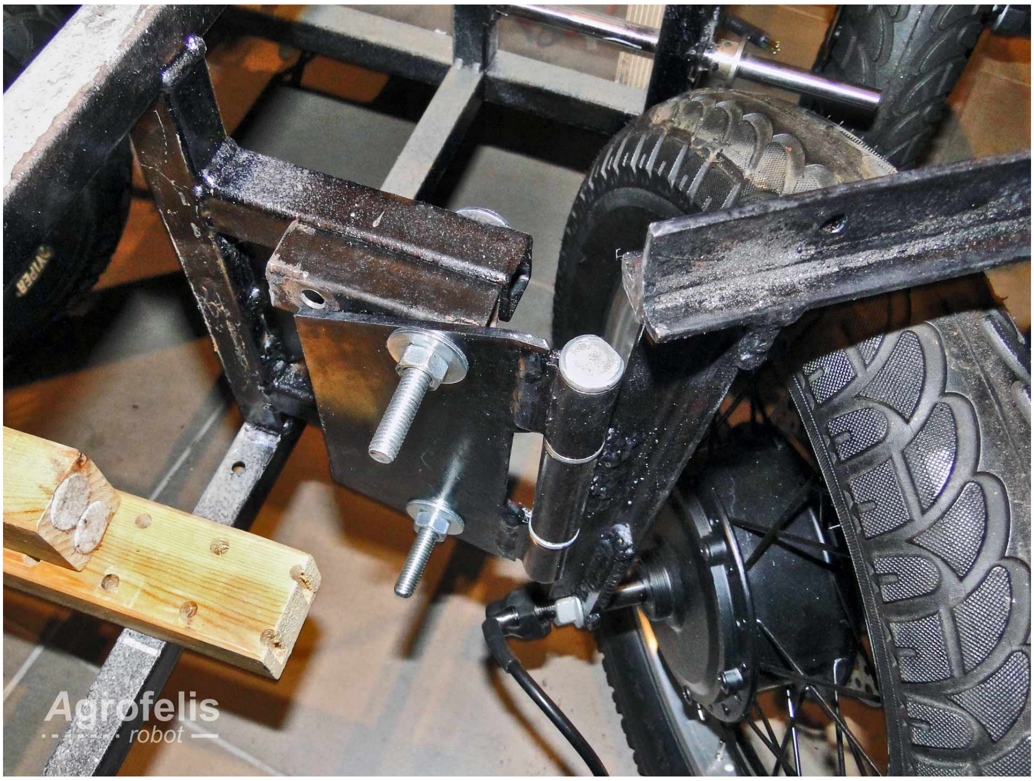

Figure 16: Hinge mount fabricated view c

A bottom side focused view of the related mechanism after it has been painted is provided by the next image.

Figure 17: Hinge mount fabricated view d

A close-up photo revealing the dropout element of the fork with a disk brake attached to it, is displayed by the following photo.

Figure 18: Hinge mount fabricated view d

Forks Components and Indicative Suppliers

The following table lists the individual components employed for manufacturing the four Agrofelis forks and their mounting mechanism. The index table includes moreover the product URLs, the indicative suppliers, as well as the total unit price amounts.

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#1	4 meter black iron T bar 25 x 3	T bar	QOOP Metalworks	1	24.00	24.00	-
#2	Black iron metal sheet 1000x2000x3mm	3mm metal sheet	QOOP Metalworks	0	73.85	0.00	Already accounted in the chassis frame bill and material
#3	Black iron metal sheet 600x400x4mm	4mm metal sheet	QOOP Metalworks	1	15.00	15.00	-
#4	Bolt 12mm X 50mm	Bolt 12mm X 50mm	Vida	4	0.70	2.80	-
#5	30 Nuts pack 12mm	Nuts 12mm	Flextools	1	1.50	1.50	-
#6	Welded Hinge with 3 winds	Hinge	Schmiedekult	2	5.00	10.00	-
Total						**53.30**	

The total cost to manufacture four Agrofelis forks, exclusive of shipping and assembly expenses, totals approximately **53** euros.

Summary

The development process, component details, essential dimensions and Numerical Control source files for reproducing the Agrofelis wheels forks have all been documented in a progressive manner. To conclude, an image depicting the vehicle with a focus on its front and back forks is presented below.

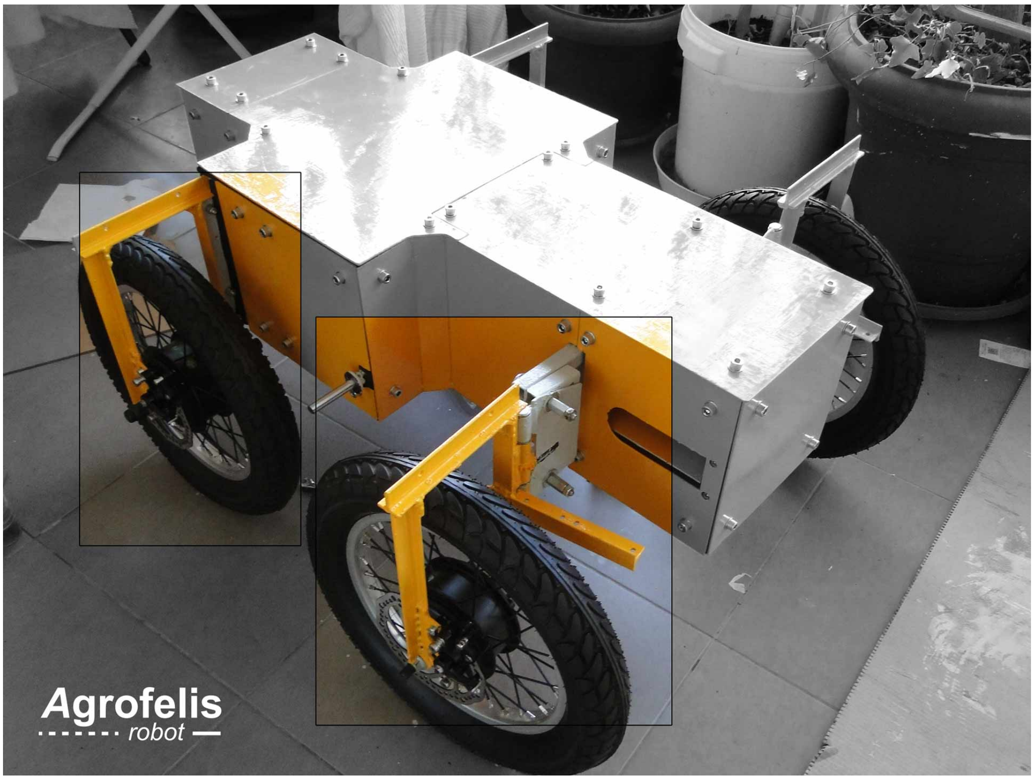

Figure 19: Vehicle with focus on the forks

End of document

Agrofelis Power System Design and Fabrication

Documentation

Agrofelis

Document created on 2023-10-09 04:14:58

Abstract

This document delves into the power-related components that classify the Agrofelis robot as an energy-dense solution. The battery technology employed, as well as the capacity, management, monitoring, and charging options, are elaborated. The battery arrangement for minimizing the vehicle's footprint, as well as its protective enclosure and cable connectivity schematics, are all documented. In addition, the power distribution, the different voltages energizing the various electronics, along with the protective mechanisms are documented. Furthermore, the document describes the WiFi relays and how to make them more robust. The documentation also lists all the utilised components, their prices, along with indicative suppliers facilitating the reproducibility of the system.

Contents

Introduction

The power module and its sub-elements is the most expensive module of the Agrofelis robot. A large 8 kW battery system was chosen in order to allow for an 8-hour shift under moderate energy consumption, with a work load peaking between 500 and 1000 watts. The most recent and extensively utilized form of battery employed in off-grid solar panel systems, known as LiFePO4 (Lithium Iron Phosphate), was chosen. This type of technology was chosen because of its extraordinary longevity, high discharge rate, environmental friendliness, safety features, low toxicity, steady performance at variable environmental conditions, and thermal and chemical resilience.

A wide range of sensors were incorporated into the Agrofelis robot, which enabled the monitoring of the total discharge rate of the system as well as the power consumption of the individual components and actuators. The usage of various energy feedback sensors allows intelligent management of the system within the range of its highest efficiency, thus prolonging its lifetime and the runtime of the robot.

Passive systems, which are commonly used in the automotive sector, as well as active systems, were installed in the energy-demanding routes of the system, protecting the rest of the electronics and modules in the event that a component failed un-expectedly.

In the following sections, the overall energy system is being decomposed to its layers, its elements and their details.

An overview of the vehicle, its batteries and their compartment can be seen via the following schematic.

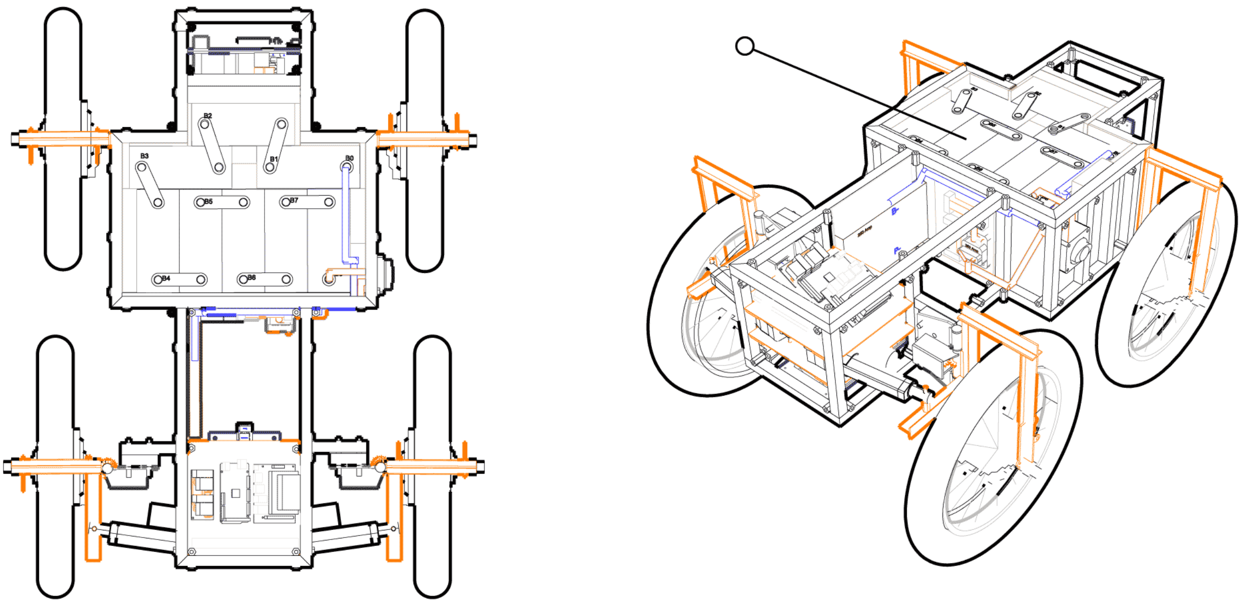

Figure 1: Power overview

Batteries

The battery technology chosen for the Agrofelis robot centers around Lithium Iron Phosphate (LiFePO4) battery cells[1]. Because of their safe operation, low toxicity and long life lifetime, LFP batteries are finding a number of roles in vehicle use, utility-scale stationary applications and backup power systems[2]. Eight CATL 302Ah LiFePO4 battery cells (LEP71H3L7-01) connected in series, make up the battery stack of the vehicle.

Each cell approximately weights 5.5 kg, possess a voltage range of 2.0V to 3.65V with a nominal voltage of 3.2V, while able to operate between -35 and 65 degrees Celsius. Their life cycle exceeds 4000 charge/discharge cycles corresponding to nearly 11 years, if the robot is operated once a day. The battery's lifespan can also be extended if the depth of charge and discharge rates are bounded to lower levels than their maximum. The batteries offer a nominal discharge rate of 0.5C and a maximum continuous rate of 1.0C. This means that the batteries can effectively deliver constantly 150 amps and peak safely up to their nominal amp power (302Ah+).

The typical dimensions of a 302Ah battery cell are encoded by the following image.

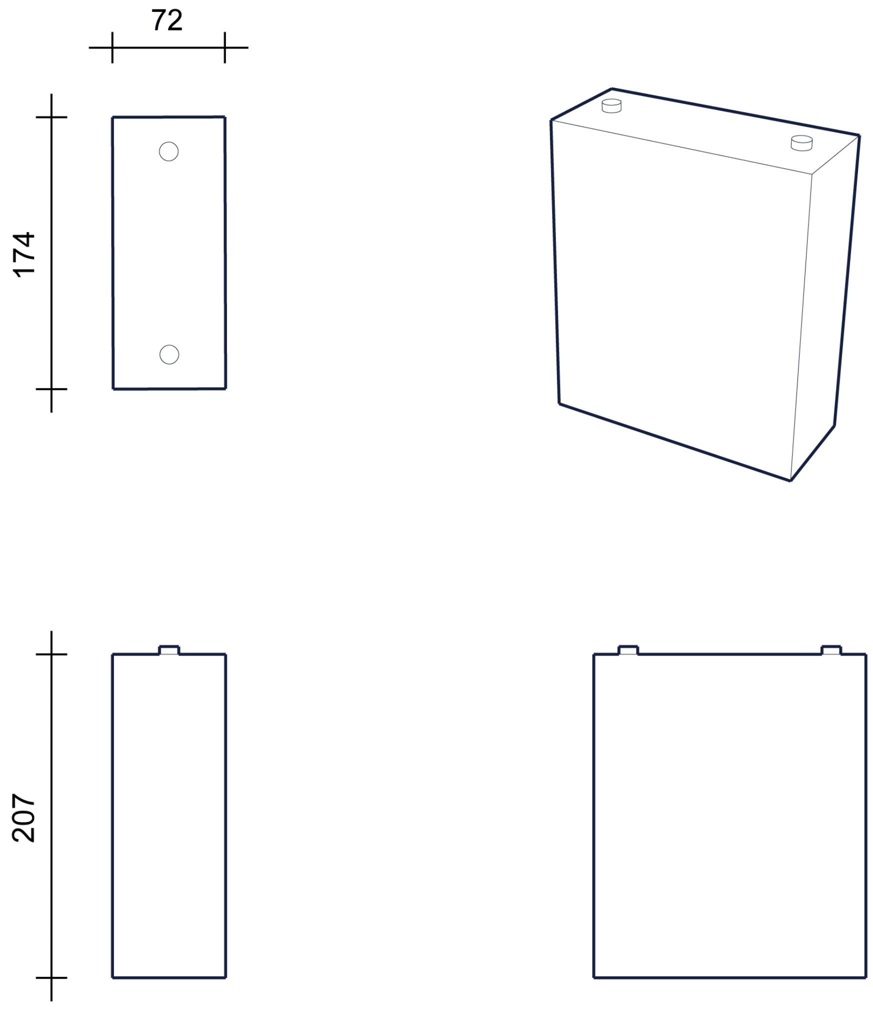

Figure 2: Battery cell

[1] https://www.anker.com/blogs/battery/lifepo4-battery-benefits-and-uses-you-should-know "Benefits and Uses You Should Know"

[2] https://en.wikipedia.org/wiki/Lithium_iron_phosphate_battery "Wikipedia - LiFePO4"

Batteries Arrangement

The following diagram illustrates the unusual battery arrangement, allowing a width reduction for the frame by about 20 cm.

The battery poles, connected with the BMS voltage sensor cables, are labeled from B0 to B8. B0 represents the negative pole of the first battery and B8 corresponds to the positive pole of the last battery in the sequence. Each battery cell is connected in series such that the positive pole of one cell meets the negative pole of the consequent cell and vice versa. Connecting the batteries in series accumulates their voltage while maintaining a constant amperage.

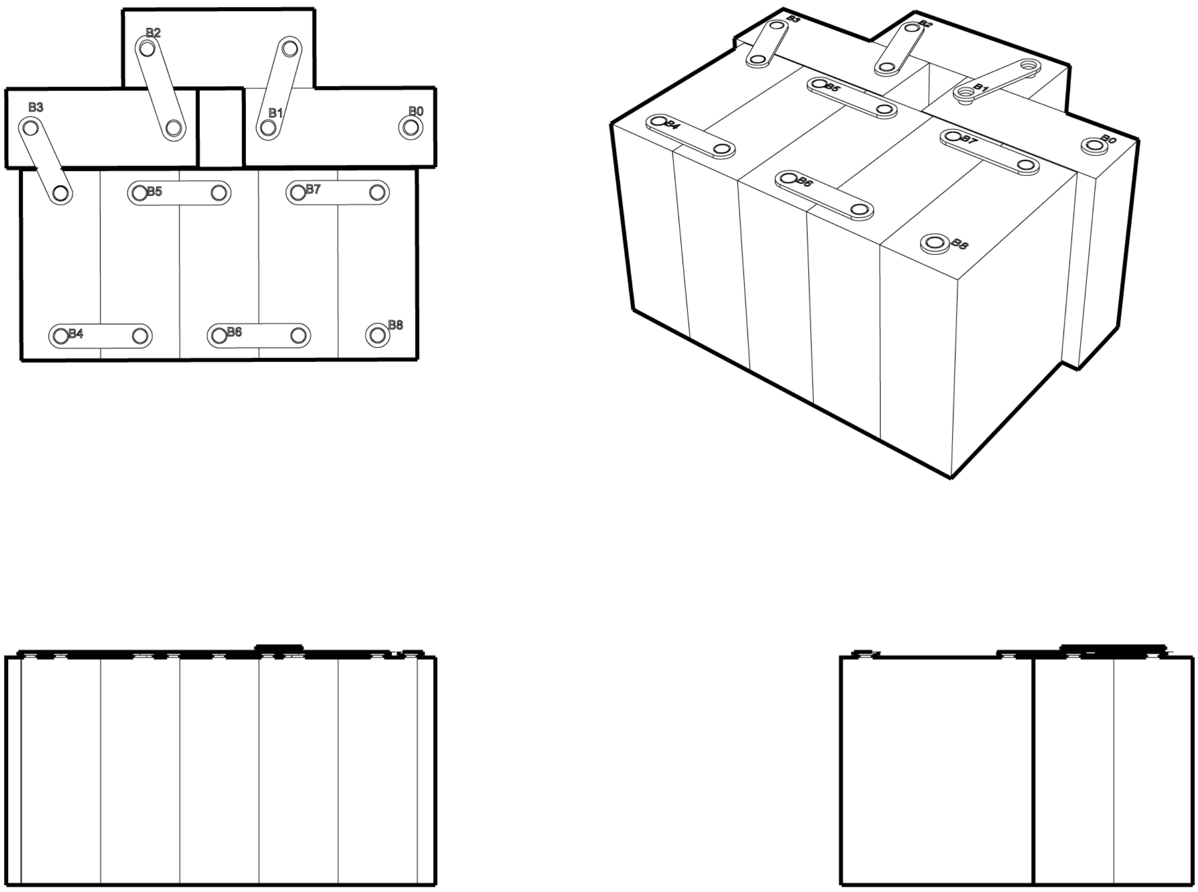

Figure 3: Batteries arrangement

A photo of the batteries while drafting their arrangement is displayed below.

Figure 4: Batteries arrangement actual

Batteries Hardening and Protection

The majority of the batteries, particularly those facing the outer side of the structure, were dressed with 1.5 mm battery insulating barley paper, hardening their outer shell even further.

Batteries Fitting and Isolation

Pieces of wood (plywood) were utilised to encase the batteries within the frame, shielding them from external temperature variations, compensating for minor accumulative dimension differences either in the batteries or in the fabrication of the frame and having a softer material than metal touching the batteries is better, as it can also serve as a subtle shock absorber.

The wood boards fit tightly and gently in order to allow compressing forces on the batteries, preventing them from expanding during their charging and discharging cycles, which prolongs even further their lifetime. Lack of compression causes cell damage, as indicated by swelling and premature battery failure[3].

The consequent figure illustrates the batteries along with their wooden separators. On the right side of the structure a route is created to pass the high-current outlet cables.

3 https://www.currentconnected.com/learning-center/lc-stor/llfp-comp/ "LiFePO4 Cell Compression"

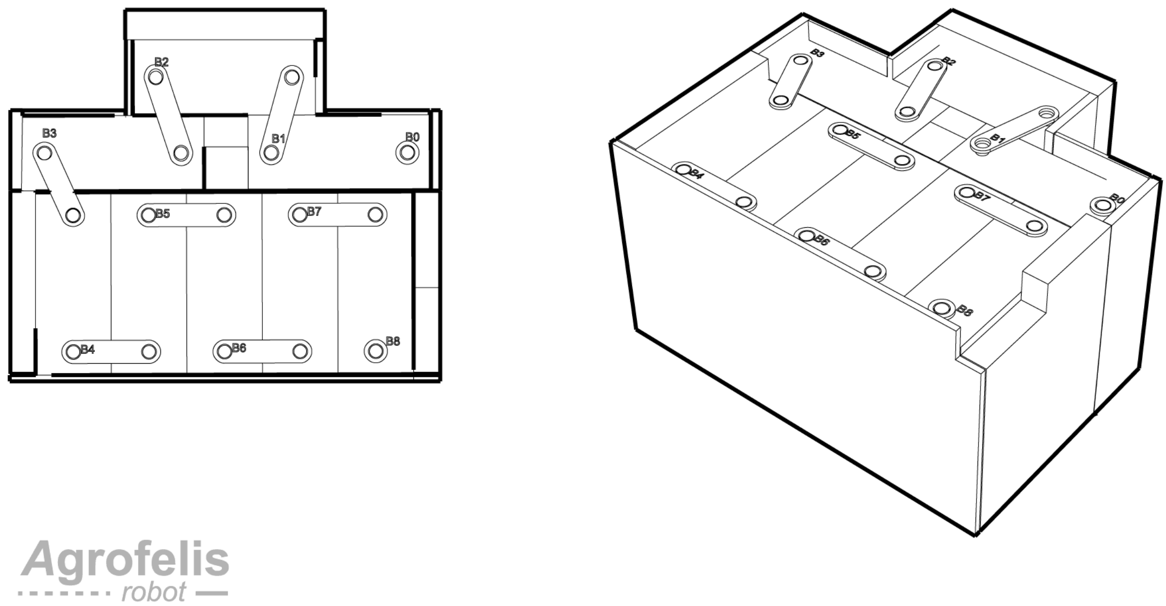

Figure 5: Batteries wood covers

The following diagram illustrates and enumerates the ten plywood pieces that fill the designed gap created by the batteries and the frame compartment.

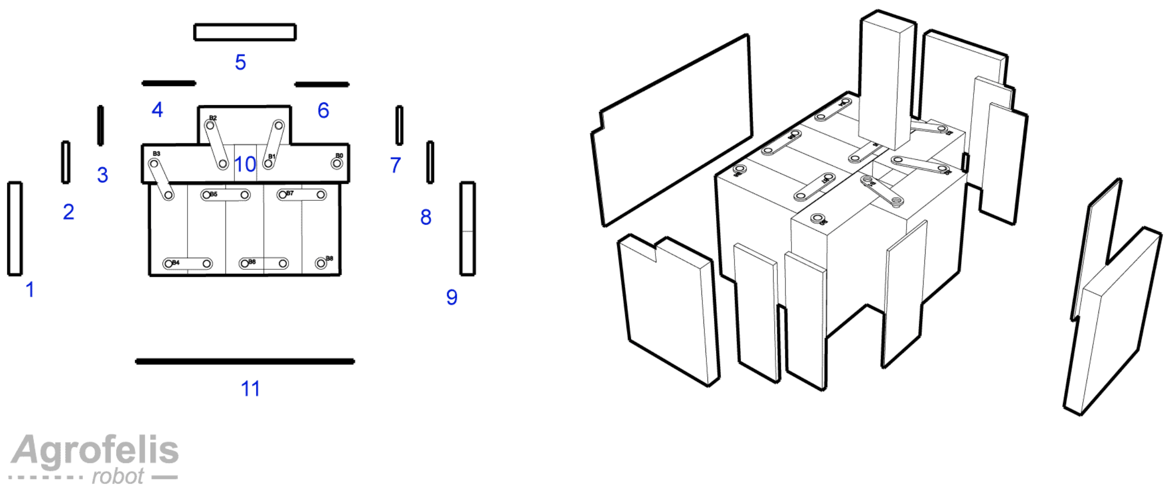

Figure 6: Wood pieces exploded

The 10th piece, which is inserted last, secures the batteries when they are in place and aids in the removal of the batteries when they are removed. The backside of the battery compartment neighboring with the back compartment of the vehicle is isolated using a plexiglass piece (part 11) because of its flexibility and durability.

The enumerated wooden pieces, together with their dimensions and thickness are documented by the following schematic.

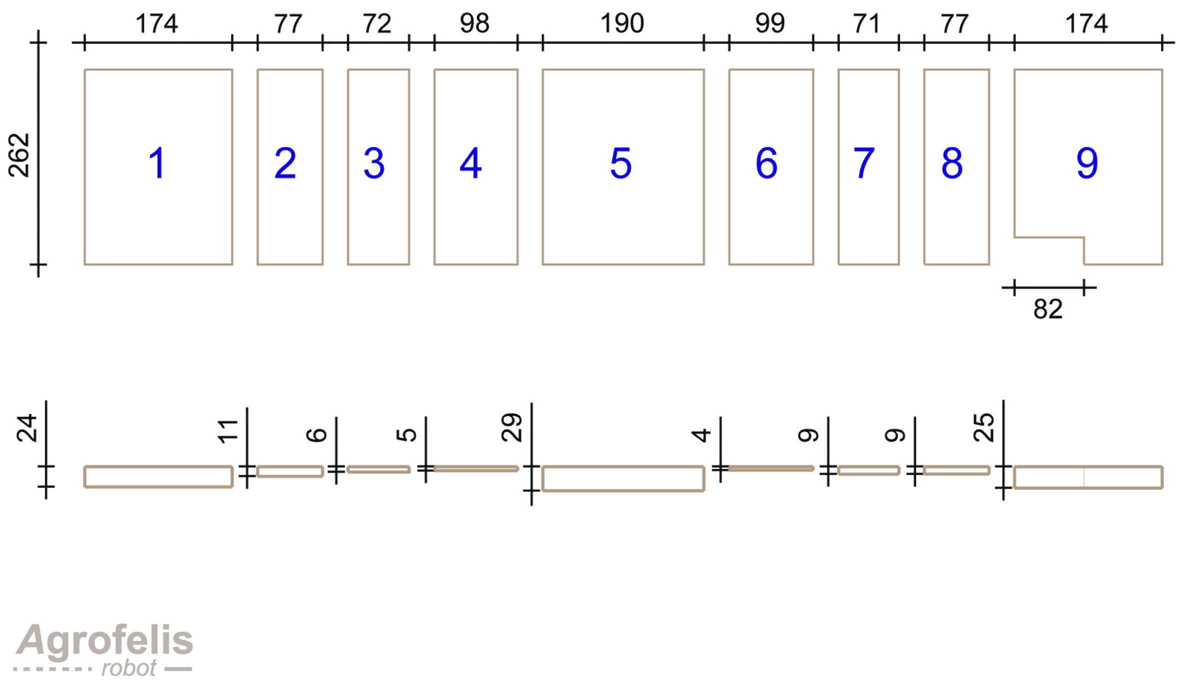

Figure 7: Wooden pieces dimensions

The 11th part, made out of plexiglass dimensions, is encoded by the following diagram.

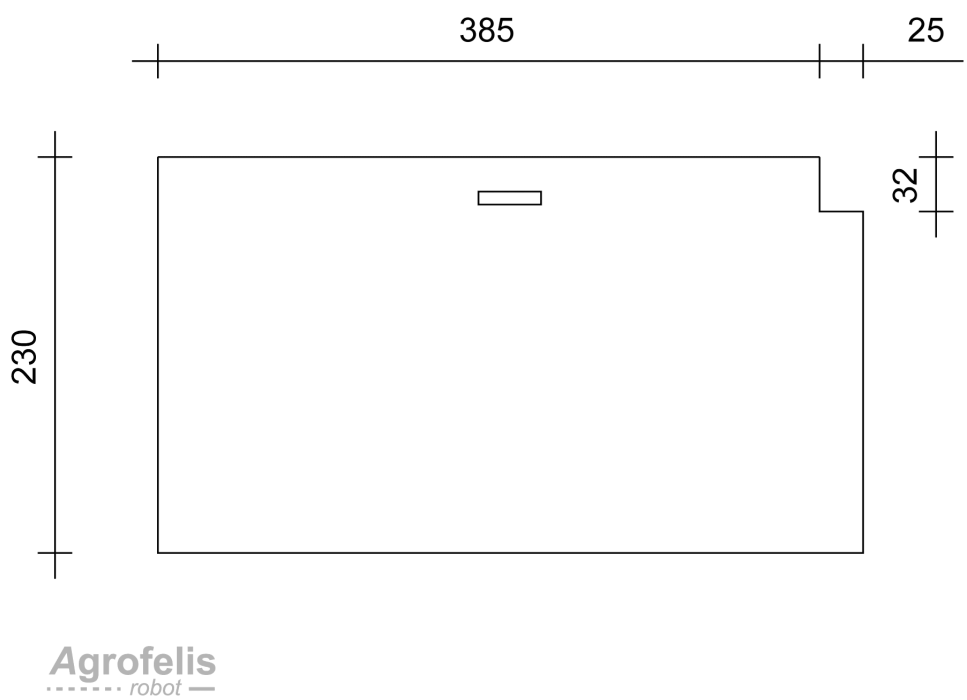

Figure 8: Plexiglass separator

A hole in the plexiglass's top center position, just under the frame bar, is drilled to pass the battery temperature sensor, the battery cells voltage regulators, as well as the power wire supplying electricity to the front section of the vehicle.

The following photograph showcases the aforementioned details of the implemented battery module.

Cables passing through part 11, including voltage sensor cables, temperature sensors, power and data cords connecting to the front section of the vehicle, as well as B8 and B0 battery poles corresponding to the positive and negative outlet of the battery pack, can be seen. Furthermore, the photo displays the painted wooden pieces enriched with a film of Kapton tape, which makes them waterproof and resistant to extreme temperatures (269 to +400 °C)[4].

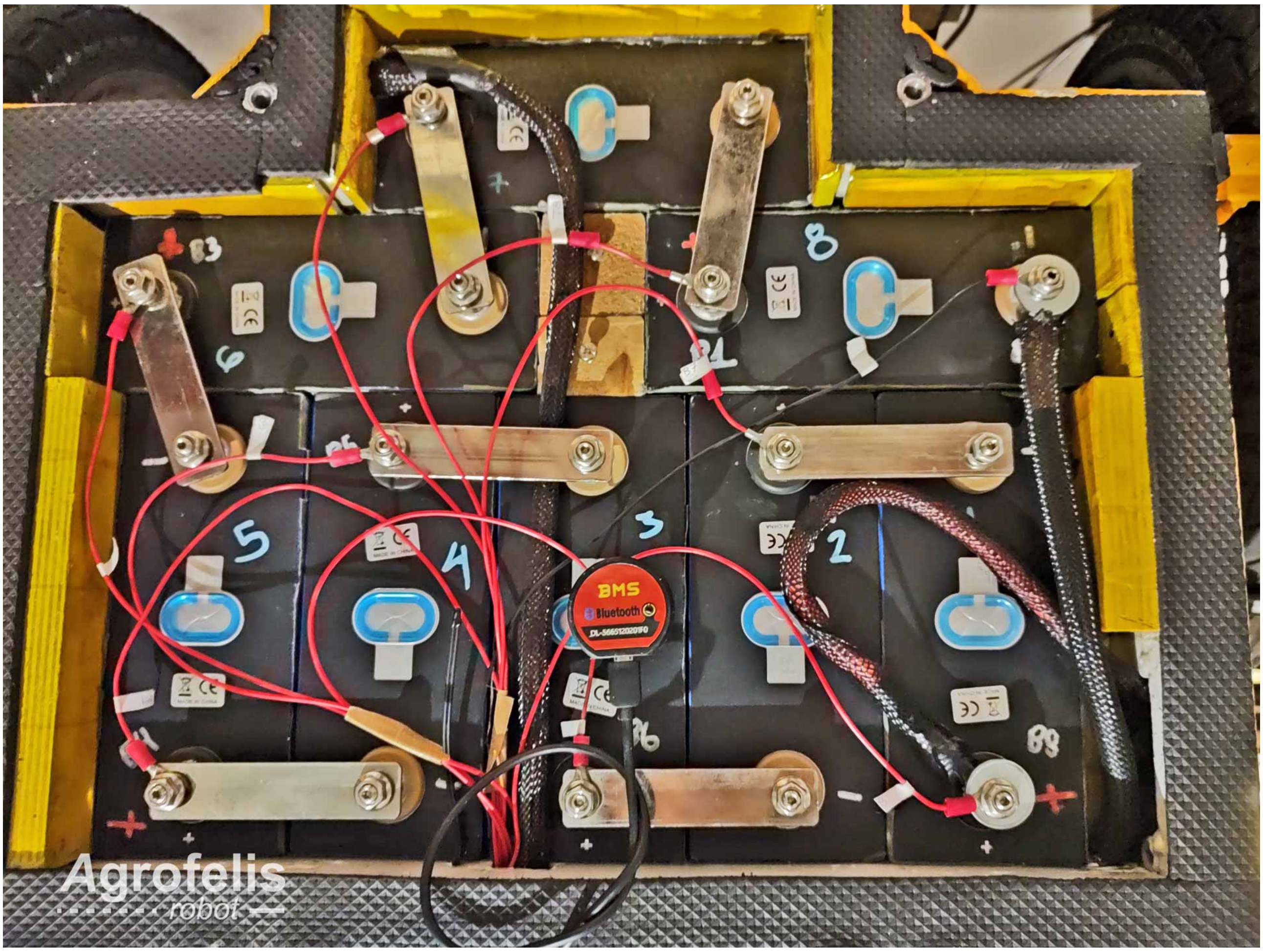

Figure 9: Batteries enclosed

Battery Management System

The following photo shows the heavy-duty Battery Management System (BMS) , which is responsible for monitoring and controlling the charging and discharging processes per battery cell in a balanced manner. Maintaining a voltage balance across the battery cells preserves and prolongs the lifetime and stability of the battery pack. The BMS can moreover detect a short circuit, identify a faulty battery cell and prevent overcharging or overdischarging of individual battery cells. The BMS thresholds can be altered and the monitoring data can be accessed either via Bluetooth or a serial interface. On the left side of the figure we can see the voltage sensing cables. On the bottom left side we can see the temperature sensor cable being next to the Bluetooth and serial interface sockets of the BMS.

[4] https://en.wikipedia.org/wiki/Kapton "Kapton - Wikipedia"

Figure 10: BMS

The following zoomed-out view of the BMS snapshots the UART module, the Bluetooth module as well as the voltage sensor cable connections. On the top and bottom right sides we can also see the main connection outlets of the BMS connected with the negative pole of the battery pack. The BMS intercepts the negative outlet of battery pack with the B- annotated cable (blue) and connects the rest of the circuit using the P- black annotated cable.

Figure 11: BMS with peripherals

In order to have the B- and P- outlets facing the opposite side than their original orientation, they were unscrewed and re-mantled on their opposite side, so they now conveniently face the same direction as the BMS sensor sockets, resulting in shorter cable and less losses within the vehicle. The BMS is established using the piece of acrylic mounted on the left side frame bars of the vehicle's back compartment.

Although the *battery module* can discharge at a maximum rate of 300 to 320 amps, as the robot's intended usage is not to operate at these currents, a slightly lighter but still heavy 250 Amp BMS was chosen instead to lower the cost and space.

High Current Components

The following diagram reflects the BMS outlet re-arrangement modification as well as the various high-current elements of the power system.

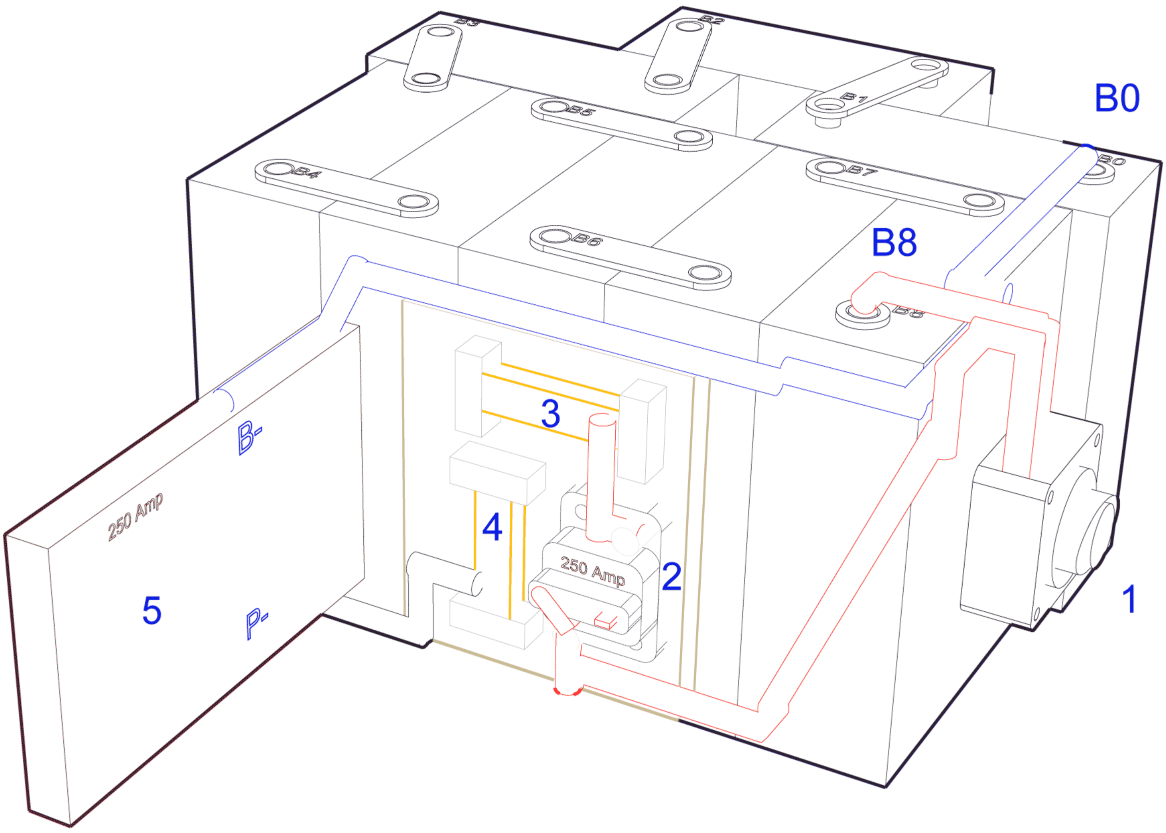

Figure 12: Components

More specifically, the enumerated parts correspond to the following elements.

1. 275 Ah battery disconnect switch
2. Circuit breaker 250A
3. Positive voltage copper bar terminal power distribution
4. Negative voltage copper bar terminal power distribution
5. Battery management system

The following photo snapshots the copper bar terminal power distributurs and the 250A circuit breaker.

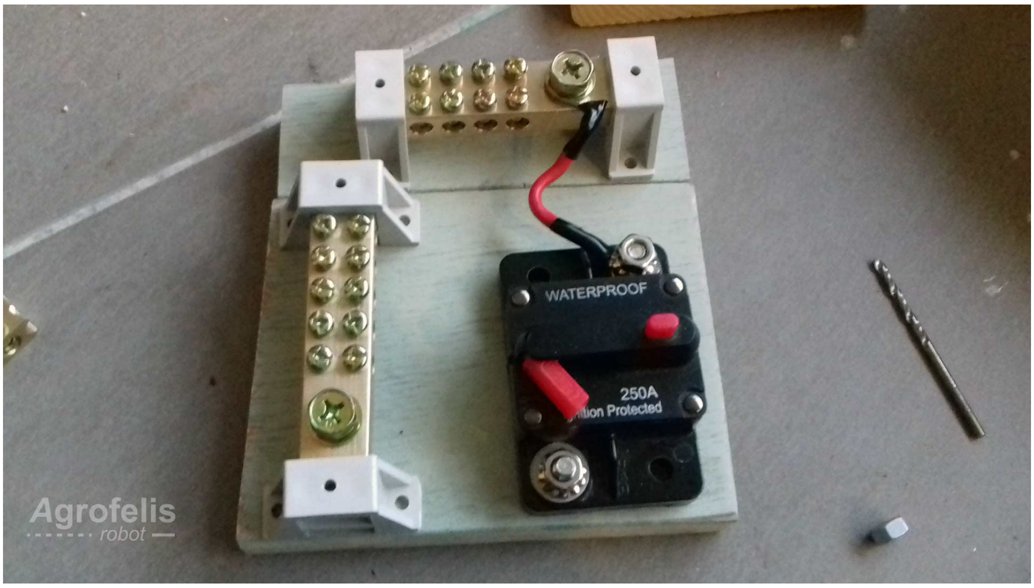

Figure 13: Breaker and bar terminals image

The subsequent photograph captures the battery disconnect switch, the BMS and some of the step down converters.

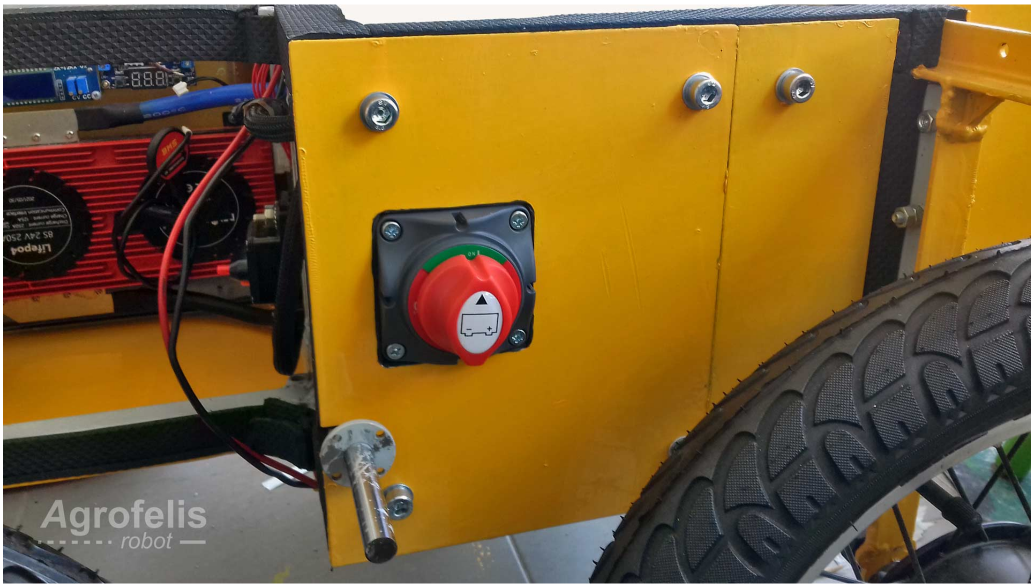

Figure 14: Battery switch image

Despite the fact that various protection mechanisms are incorporated downstream and by the BMS, the circuit breaker provides a mechanical fail safe protection mechanism at the nominal maximum levels of the energy module.

Charging

Charging the battery is accomplished by tapping into the positive and negative copper bar terminal power distributors. Two high-current cable are attached with the terminal and an Anderson[5] connector. The Anderson connector is conveniently located on

[5] https://en.wikipedia.org/wiki/Anderson_Powerpole "Anderson Powerpole - Wikipedia"

the inner side of the door, allowing easy access to the socket for charging or connecting external implements. A moderate 40A, 29.2V LiFePO4 battery charger was chosen for its cost-effectiveness and relatively acceptable theoretical charging time of less than 6 hours. Provided a larger battery charger of 150 amps, matching the maximum charging capacity of the system, would complete a charging cycle within 1.5 hours.

The following photo showcases the 40amp/29.2Volt LiFePO4 battery charger.

Figure 15: Battery charger

The charging point and how the Anderson connector is attached in the side door panel can be observed by the following figure.

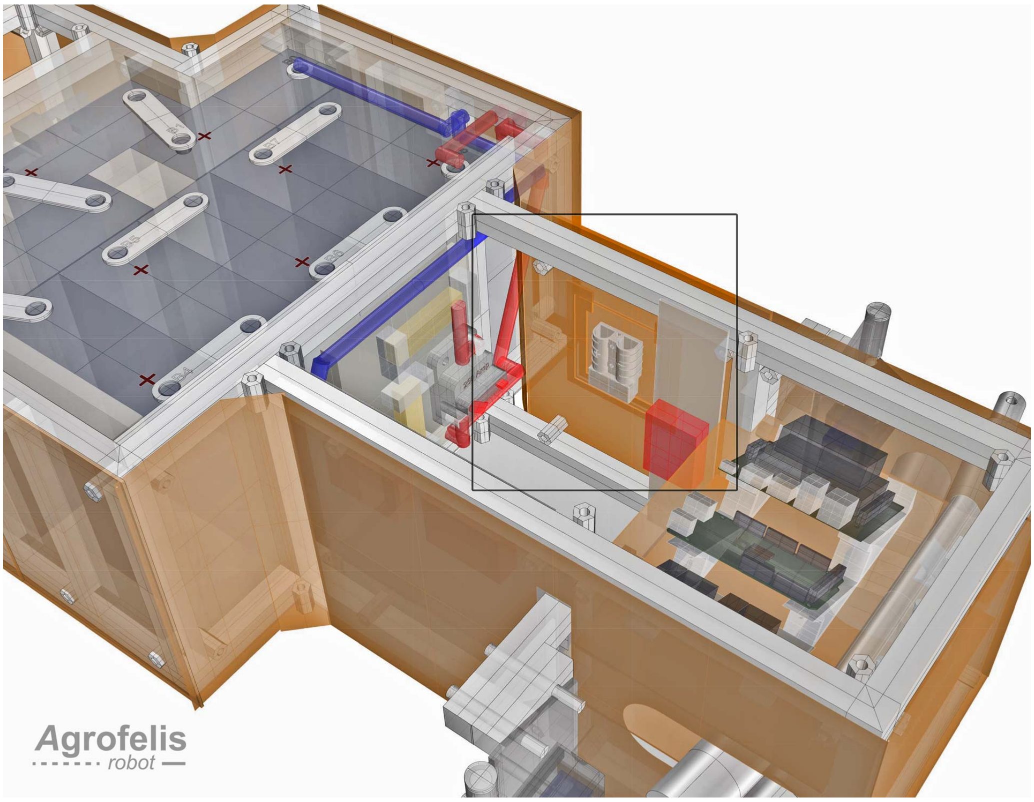

Figure 16: Anderson

Voltage Levels

The modules of the system operate either on 5V, which is used in most of the electronics and servos, or on 12V, which is used in high current relays and fans, or on the battery pack voltage level for energizing the motors and other actuators of the robot.

Three step-down voltage regulators are installed to power these modules. The first two are installed on the backside of the BMS's acrylic mount, and the third uses a small piece of acrylic with magnets facing the BMS. The first regulator steps down the voltage to 5V, the second to 12V and the third, dedicated for the servos actuating the disc brakes, steps down to 5V. The position of the step down regulators can be seen in the following diagram.

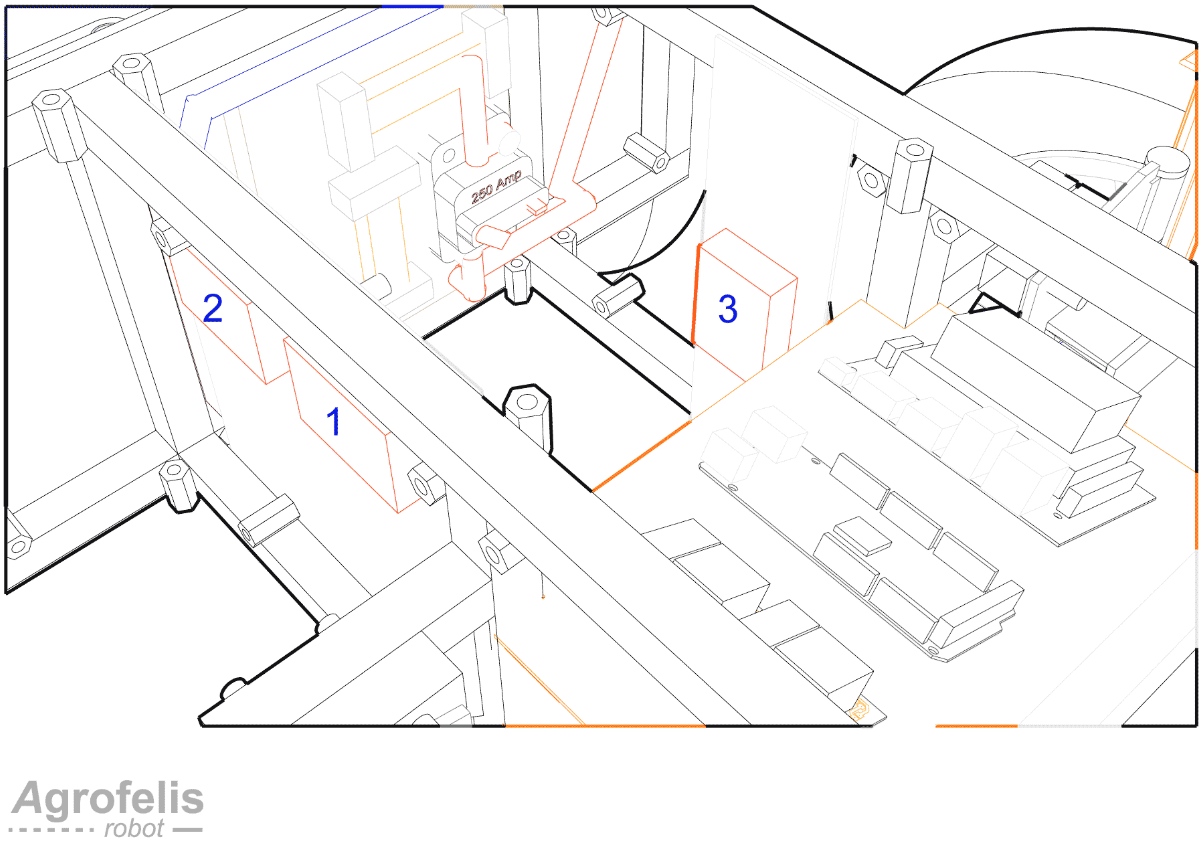

Figure 17: 07-step-down-converters

A power cord composed of two high-current cables (carrying battery voltage), four low-current cables (5V, 12V) as well as an 8-pin ribbon cable distributes power and establish a data link between the back and front compartment of the vehicle. To enhance its performance and safety, the composite power cord is wrapped with Copper Foil Tape to shield against electromagnetic interference (EMI) and then encased in a Flame-retardant PET tube Cable Sleeve. While wrapping the data cables with copper tape may seem somewhat excessive, the cables obtain a stronger structure and after troubleshooting the DIY plasma cutter due to EMI interference, we felt safer to employ it in the power cord which passes through the battery compartment.

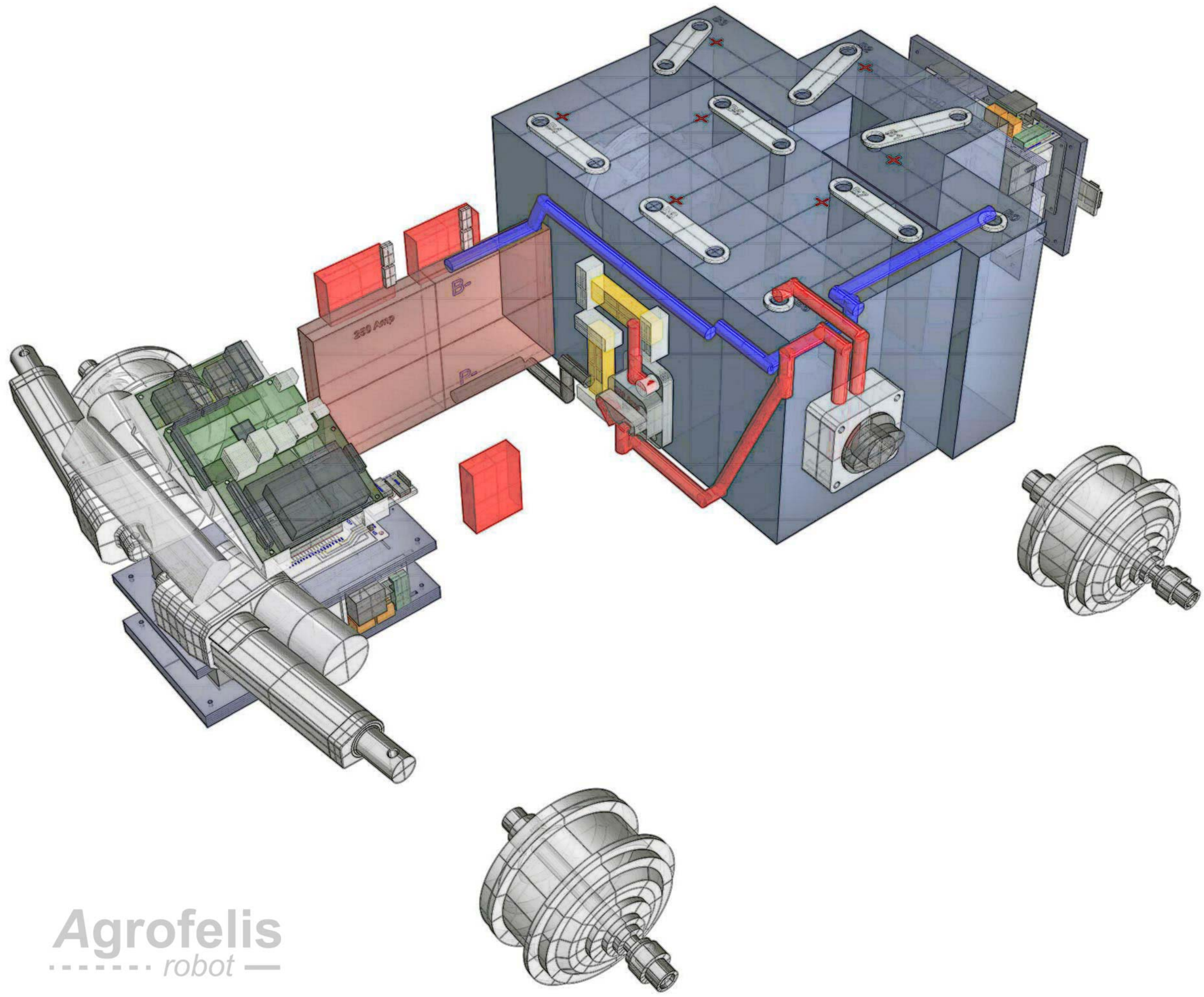

Figure 18: Electrical components

Power Cord

A power cord composed of 2 high current cables (battery voltage), 4 low current cable (5v, 12v) as well as a an 8 pin ribbon cable distribute power and provide a data link between the back and front compartment of the vehicle. The composite power cord is wrapped with Copper Foil Tape for EMI shielding and last with a Flame-retardant PET tube Cable Sleeve. Although wrapping the data cables with a copper tape may be somewhat unnecessary, the cables obtain a stronger structure and after troubleshooting the DIY plasma cutter because of EMI interference, we felt safer to employ it in the power cord which passes through the battery compartment.

The consequent image photographs the external insulation employed to the power cord.

Figure 19: Wire insulations

Switchable Power Points

Although adding more protective mechanisms increases complexity and materials, it also enables to compartmentalize the propagation of a point of failure and protect the internal components of the Agrofelis Robot. Two composite modules were designed and installed for the front and the back actuators of the vehicle.

The module employed sockets supporting burnable fuses, which are commonly used in the car industry. Fuses of almost double the maximum amperage of each actuator were chosen. The module was moreover equipped with a high-current car relay (80 Amp) that is controlled by an ESP8266 WiFi relay. Lastly, a diode was utilized to minimize the ripple back voltage effect caused by the coils of the relays when these change state. The module allows to energize connected actuators on demand. Furthermore, it permits to energize them in a staggered sequence, mitigating power spikes that might occur when all components power up simultaneously. The module enables to cut the actuator's power in case of an emergency and minimizes the power consumption while the robot is in stasis. Nevertheless, this increased agility comes with a minor trade-off, as it consumes an additional 1.5 watts of power to maintain the relay coils in an "on" state.

In the following figures the assembly of the power points module is presented.

The following figure illustrates the key component that forms the switchable main power point module.

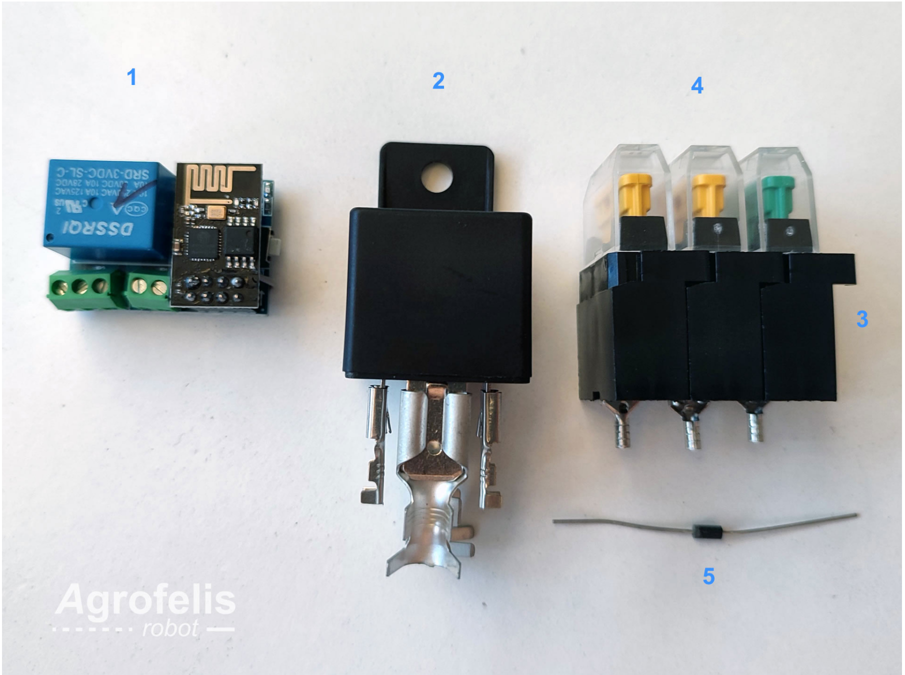

Figure 20: 15-relay-fuse-1

1. ESP8266 ESP-01/01S 5V WiFi Relay Module
2. SPDT Ucoil 80A 1.8W car relay AM3-12P
3. 3x blade fuse holder
4. 2x 20-amp and 1x 30-amp fuse
5. 1N5819 5819 1A 40V Schottky Diode

A close-up view of the high-current car relay is captured in the following photo.

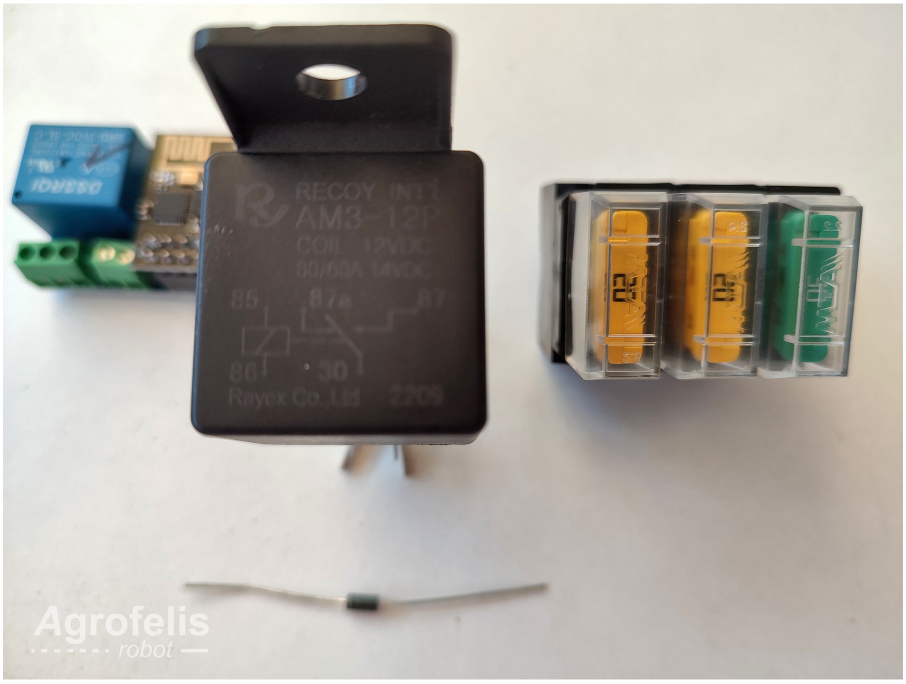

Figure 21: 15-relay-fuse-2

The relay is securely glued and connected with three blade fuse holders, fuses, and connectors, as shown in the following photo.

Figure 22: 15-relay-fuse-3

The module with the WiFi Relay Module hot glued also on the side of the relay is snapshot by the next photograph.

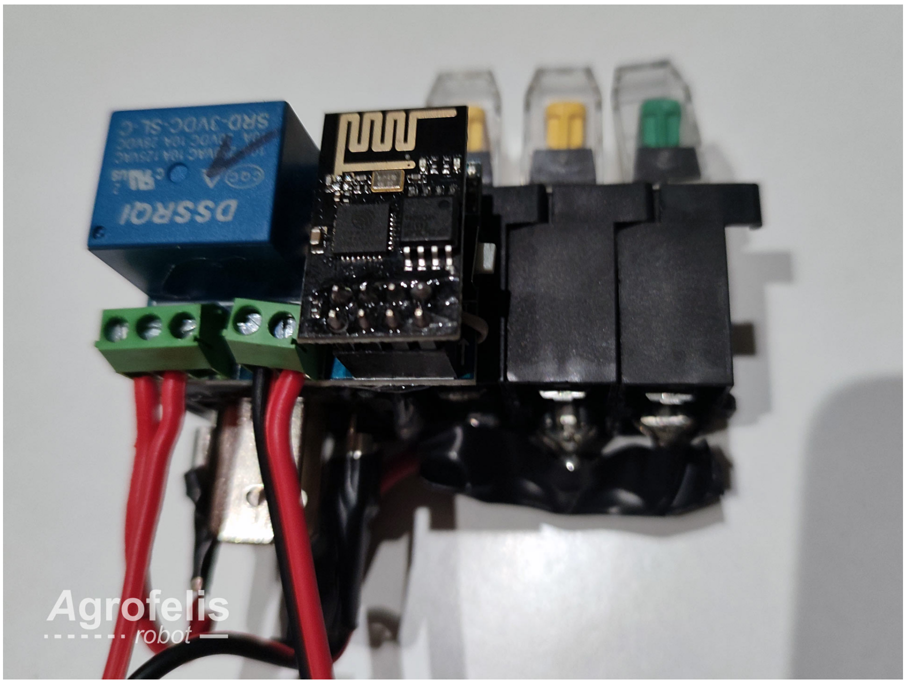

Figure 23: 15-relay-fuse-4

A side view of the completed module, attaching also a flyback[6] diode in the high-current relay as well as the connection cable, can be seen in the following photo.

6 https://resources.altium.com/p/using-flyback-diodes-relays-prevents-electrical-noise-your-circuits "Using Flyback Diodes in Relays Prevents Electrical Noise in Your Circuits"

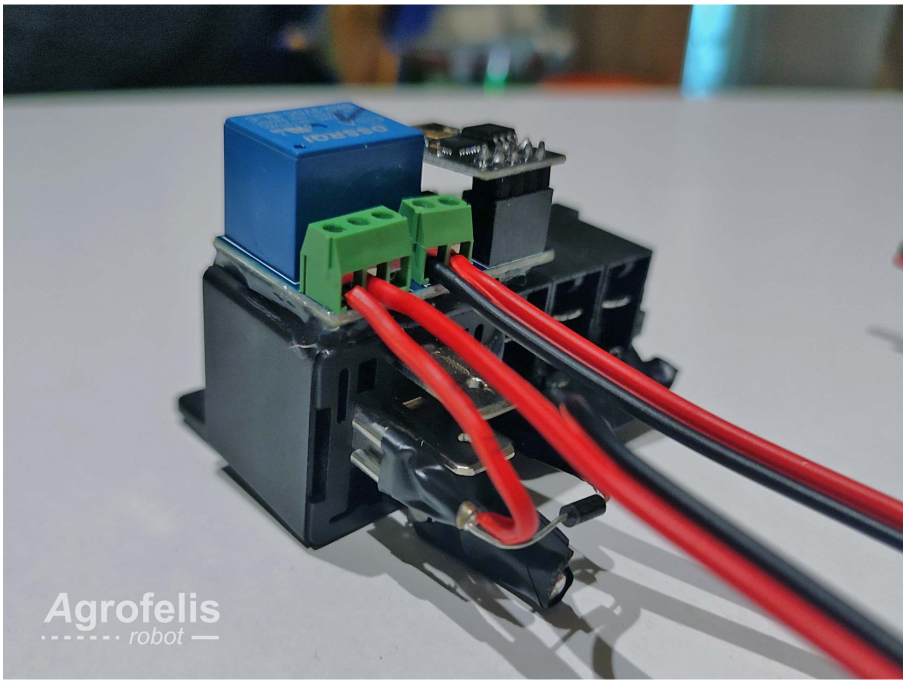

Figure 24: 15-relay-fuse-5

WiFi Relay Module

The ESP8266 ESP-01/01S 5V WiFi Relay Module includes a problematic factor in its design. The problem is that when it is powered up, it momentarily switches its relay, causing an unintended flow of energy. The issue occurs due to the pin used by the shield to turn on the ESP8266 boot. To resolve this issue, the board route to that pin must be cut using a cutting tool or small Dremel and remapped to another pin, such as GPIO3, which does not have this inherent issue. Finally, the microcontroller must be reprogrammed to utilize the new intended pin.

The solution described here was employed: https://github.com/IOT-MCU/ESP-01S-Relay-v4.0/issues/1#issuecomment-808784642

The following folder contains the ESP8266 source code utilizing the GPIO pin 3 as well as connecting to the Agrofelis robot default Wifi network.

- src/ESP8266Relay/

Power System Components

The following table lists the individual components employed for manufacturing the Agrofelis power system. The index table includes moreover the product URLs, the indicative suppliers, as well as unit prices and sum totals.

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#1	302A LiFePO4 CATL battery cells	LiFePO4	Dongguan	8	113.00	904.00	-
#2	Daly BMS LiFePO4 8S 250A Smart	BMS	AliExpress	1	160.27	160.27	-
#3	LiFePO4 8S 40A battery charger	Battery Charger	AliExpress	1	130.43	130.43	-
#4	250Ah Circuit Breaker Power	Circuit Breaker Power	AliExpress	1	5.39	5.39	-

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#5	Battery disconnect switch SLO-BDS-1	Battery Switch	AenaoShop	1	39.73	39.73	-
#6	80-amp relay	80-amp relay	Electronio	2	8.23	16.46	-
#7	Row Copper Bar Terminal Power Distribution 8 Hole, With Base	Bar Power Distribution	AliExpress	2	7.19	14.38	-
#8	70mm 10 Meter Battery Insulation	Battery Insulation	AliExpress	1	14.06	14.06	-
#9	80mm Kapton Thermal Insulation Adhesive Tape	Kapton Tape	AliExpress	1	16.35	16.35	-
#10	50M, 8mm Insulated Braided Sleeving Data line protection	Cable Protection	AliExpress	1	16.16	16.16	-
#11	Copper tape 50mm, 20M, One roll	Copper Tape 50mm	AliExpress	1	20.07	20.07	-
#12	LTC3780 DC-DC 5-32V to 1V-30V 10A Automatic Step Up Down	Step Down	AliExpress	3	7.23	21.69	-
#13	ESP8266 ESP-01/01S 5V WiFi Relay Module	WiFi Relay	AliExpress	2	1.00	2.00	-
#14	1N5819 5819 1A 40V Schottky Diode	Diode	Hellas Digital	2	0.10	0.20	-
#15	1m black and red 2awg cable	2awg cable	AliExpress	1	44.10	44.10	-
#16	2m black, red 6awg cable	6awg cable	AliExpress	2	22.10	44.20	-
#17	5m black and red 10awg cable	10awg cable	AliExpress	1	35.10	35.10	-
#18	2pcs 50A Quick Plug Battery Charging Connector	50A Anderson Connector	AliExpress	1	3.80	3.80	-
#19	328pcs Heat Shrink Tube Assortment	Heat Shrink Tube	Hellas Digital	1	3.47	3.47	Base Component
#20	10pcs Adhesive Hot Melt	Hot Glue	Hellas Digital	1	4.96	4.96	Base Component
#21	100g 0.8mm Welding Line Solder Wire	Solder	Hellas Digital	1	5.46	5.46	Base Component
#22	Wago 5 Way Electrical Wire Connector	Wire Connector	Hellas Digital	4	1.00	4.00	-
#23	USB To RS232 TTL	USB To RS232 TTL	Hellas Digital	1	3.00	3.00	Programs the wifi relay
Total						**1,509.28**	

The total cost to manufacture the Agrofelis power system, exclusive of shipping and labor cost, totals approximately **1,509** euros.

Conclusion

The technology characteristics of LiFePO4, as well as their arrangement and wrapping within the Agrofelis frame has been presented. The subsequent components of the BMS, its connection details and charging apparatus have been described, as have the function and setup of fuses, diodes and relays. To conclude, an image depicting the vehicle's back compartment, hosting the BMS and other electronics, is presented below.

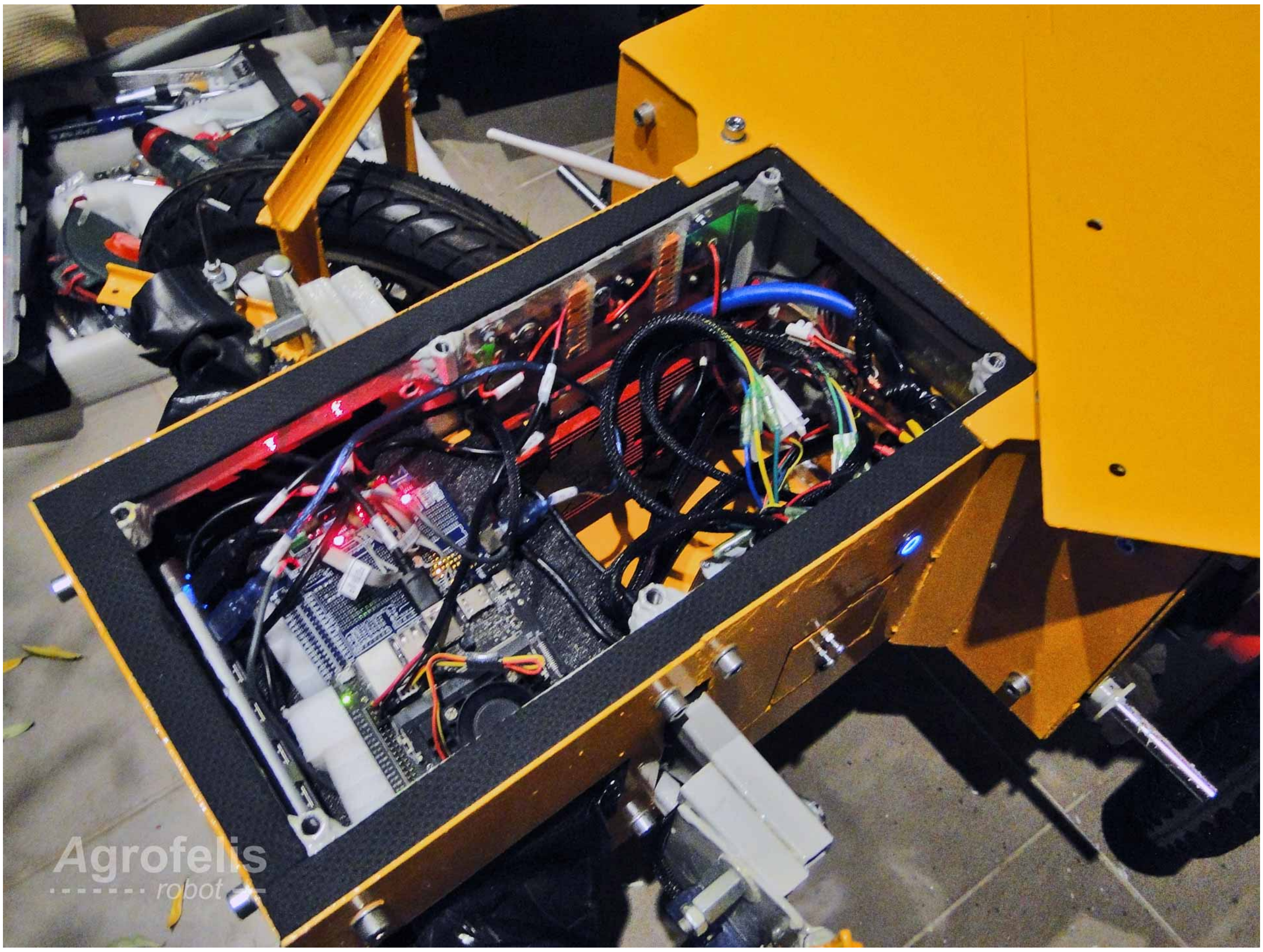

Figure 25: Close up view of the back compartment

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Agrofelis Protective Covers Design and Fabrication

Documentation

Agrofelis

Document created on 2023-10-09 04:20:58

Abstract

The document builds on the Agrofelis frame design and fabrication documentation by detailing the protective covers of the vehicle, including their schematics and the source code files utilized for a CNC plasma cutter. Additionally, photographic material offers insights into the manufactured parts. A list of components and indicative suppliers that comprise the bill and material information for isolating the robot from its external environment, is documented.

Contents

Introduction

To protect the robot from the harsh environment prevalent in agricultural fields, where dust, dirt, rocks and rain are expected, protective covers were designed and fabricated from black iron sheet of 2mm and 3mm thickness. The rigid detachable cover parts, conveniently provide access to the compartments of the robotic vehicle. The covers are secured to the vehicle using 8mm bolts, attaching to its front, back, top, bottom, left, and right sides. While the side covers are quantised by smaller parts, the top and bottom parts were manufactured with fewer and larger parts to provide additional protection by minimizing the number of intersections. The larger parts were fabricated using a grinder, while the remainder were produced with our small DIY plasma cutter.

In the following sections, the details for fabricating the Agrofelis Robot protective covers are documented.

Protective Covers

The vehicle's detachable covers amount to a total of 25 items. Most items of the left and right sides are symmetrical, with two exceptions that feature additional cavities to accommodate the vehicle's main power switch and charging socket. The following diagram visualizes the vehicle's protective covers.

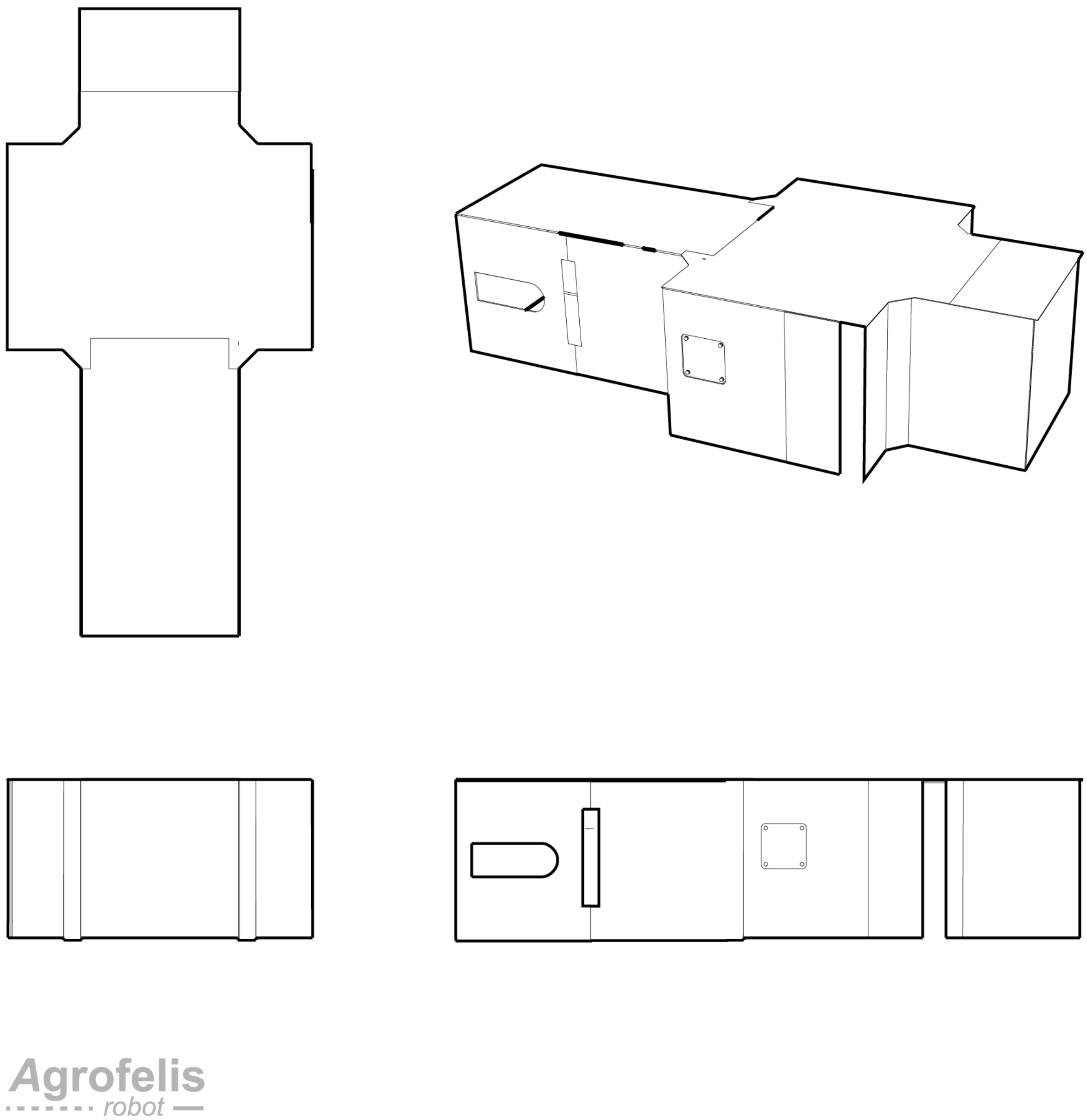


Figure 1: Covers overview

More specifically, the following schematic enumerates all plasma-cut covers. For the sake of simplicity, the symmetric left side items were omitted.

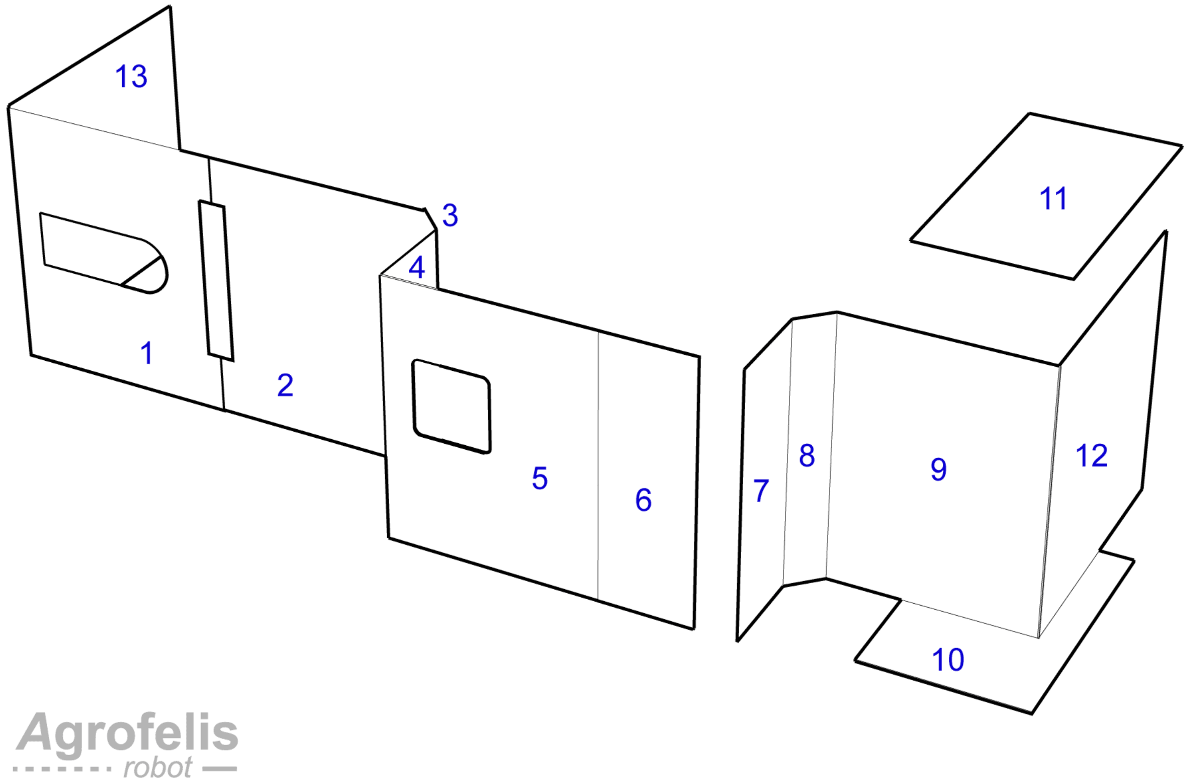


Figure 2: Covers enumeration

The consequent table, following the depicted enumeration, lists the item part, the Scalable Vector Graphic (SVG) design file and its derived Numerical Control (NC) file driving the CNC plasma cutter.

Part	Symmetrical	Side	SVG file	NC file
1	No	Right	cover_r1_normalised.svg	cover_r1_normalised.nc
1	No	Left	cover_l1_normalised.svg	cover_l1_normalised.nc
2	No	Right	cover_r2_normalised.svg	cover_r2_normalised.nc
2	No	Left	cover_l2_normalised.svg	cover_l2_normalised.nc
2	Yes	Right	cover_r2_side_door_normalised.svg	cover_r2_side_door_normalised.nc
3	Yes	Right	cover_r3_normalised.svg	cover_r3_normalised.nc
4	Yes	Right	cover_r4_normalised.svg	cover_r4_normalised.nc
5, 6	Yes	Right	cover_r56_normalised.svg	cover_r56_normalised.nc
7, 8	Yes	Right	cover_r78_normalised.svg	cover_r78_normalised.nc
9	Yes	Right	cover_r9_normalised.svg	cover_r9_normalised.nc
10	Yes	Right	bottom_front_normalised.svg	bottom_front_normalised.nc
11	Yes	Right	top_front_normalised.svg	top_front_normalised.nc
12	Yes	Right	cover_front_normalised.svg	cover_front_normalised.nc
13	Yes	Right	cover_back_normalised.svg	cover_back_normalised.nc

Non-symmetrical parts 1 and 2 are provided for both the left and right sides, while symmetrical parts 3-9 are provided just for the right side since they are identical to their left counterparts.

Part 2 on the right side also includes the design blueprint for fabricating a side door with its sealing cover, as depicted in the following diagram. The side door is used to provide access to the charging socket of the vehicle.

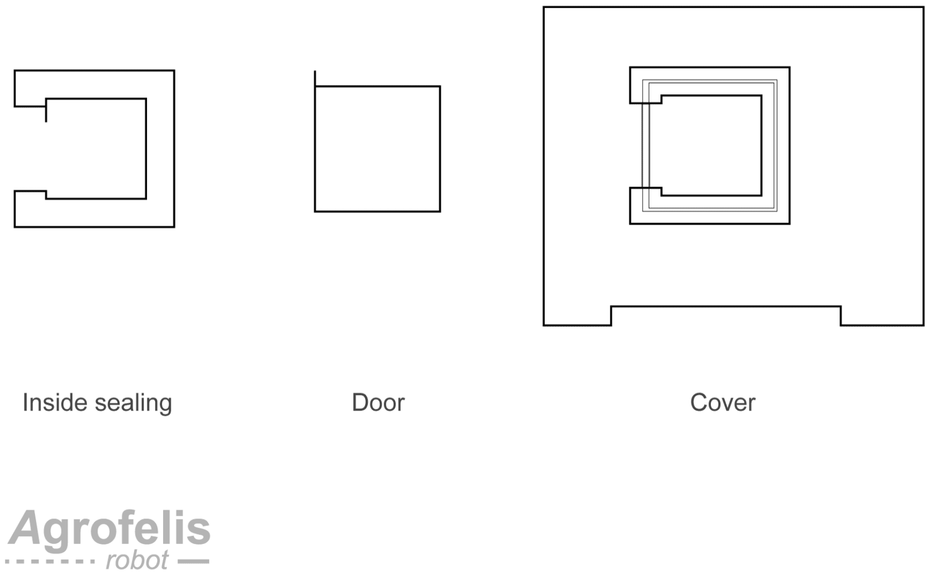


Figure 3: Cover side door

The fabricated side door, as seen from within the vehicle, can be viewed in the following photograph.

Figure 4: Door photo internal

Likewise, the next photograph displays the door from its outer side.

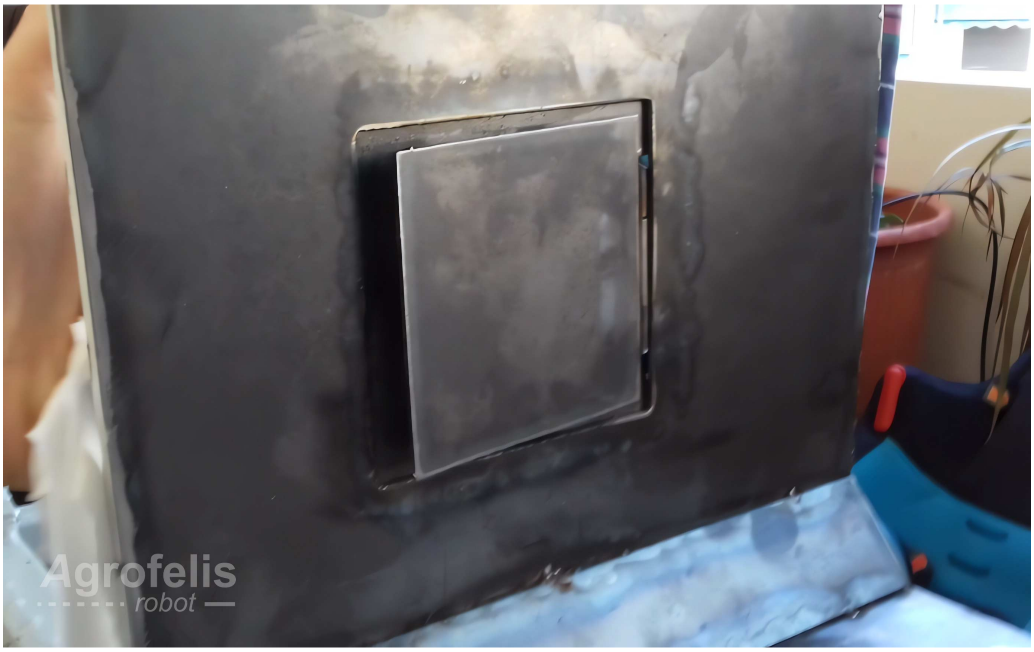


Figure 5: Door photo external

The following diagram lays out all covers made out of a 2mm thickness iron sheet. It also outlines the approximate area these covers occupy within a standard metal sheet profile of 1 by 2 meters.

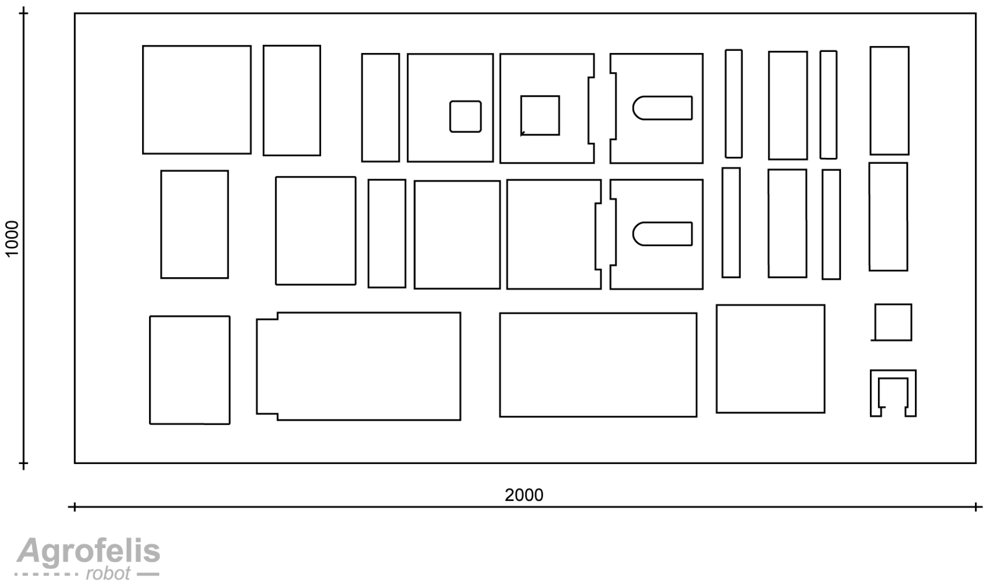


Figure 6: Metal sheet 2mm covers

The following photograph shows the plasma cutter fabricating the left-side part 2 cover.

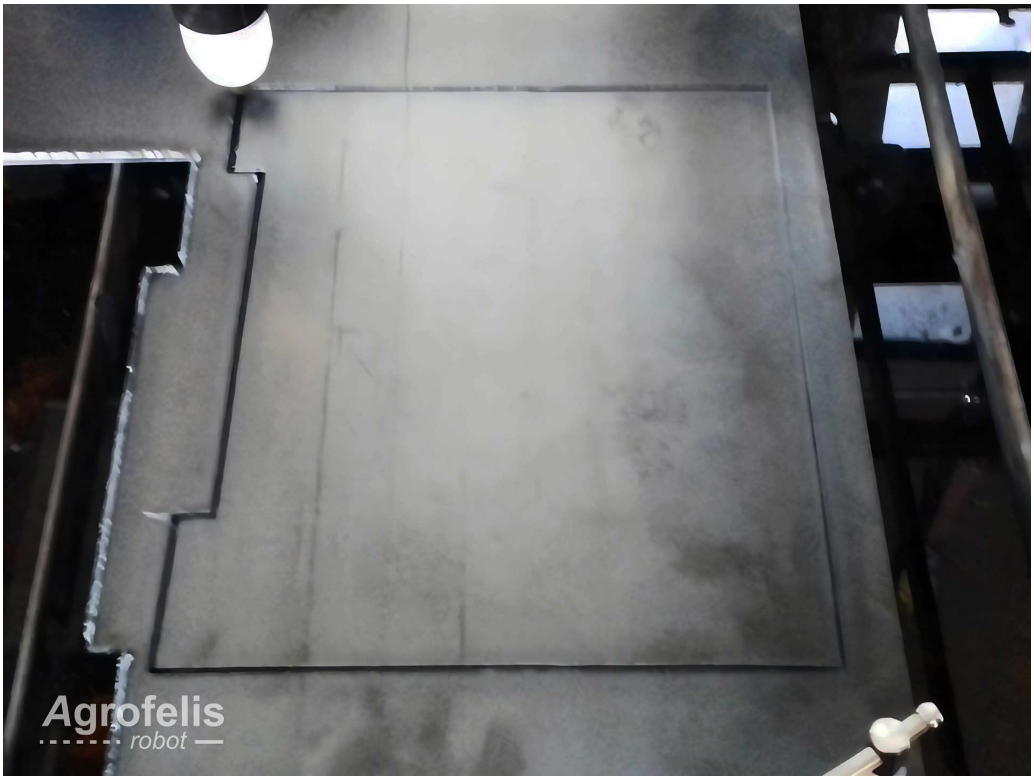


Figure 7: Plasma cut photo a

To provide additional protection, a 3mm black iron sheet was employed to completely overlay the battery compartment. The following schematic encodes the dimensions for the cover's silhouette, which had to be fabricated manually due to its size exceeding the capacity of our DIY plasma cutter.

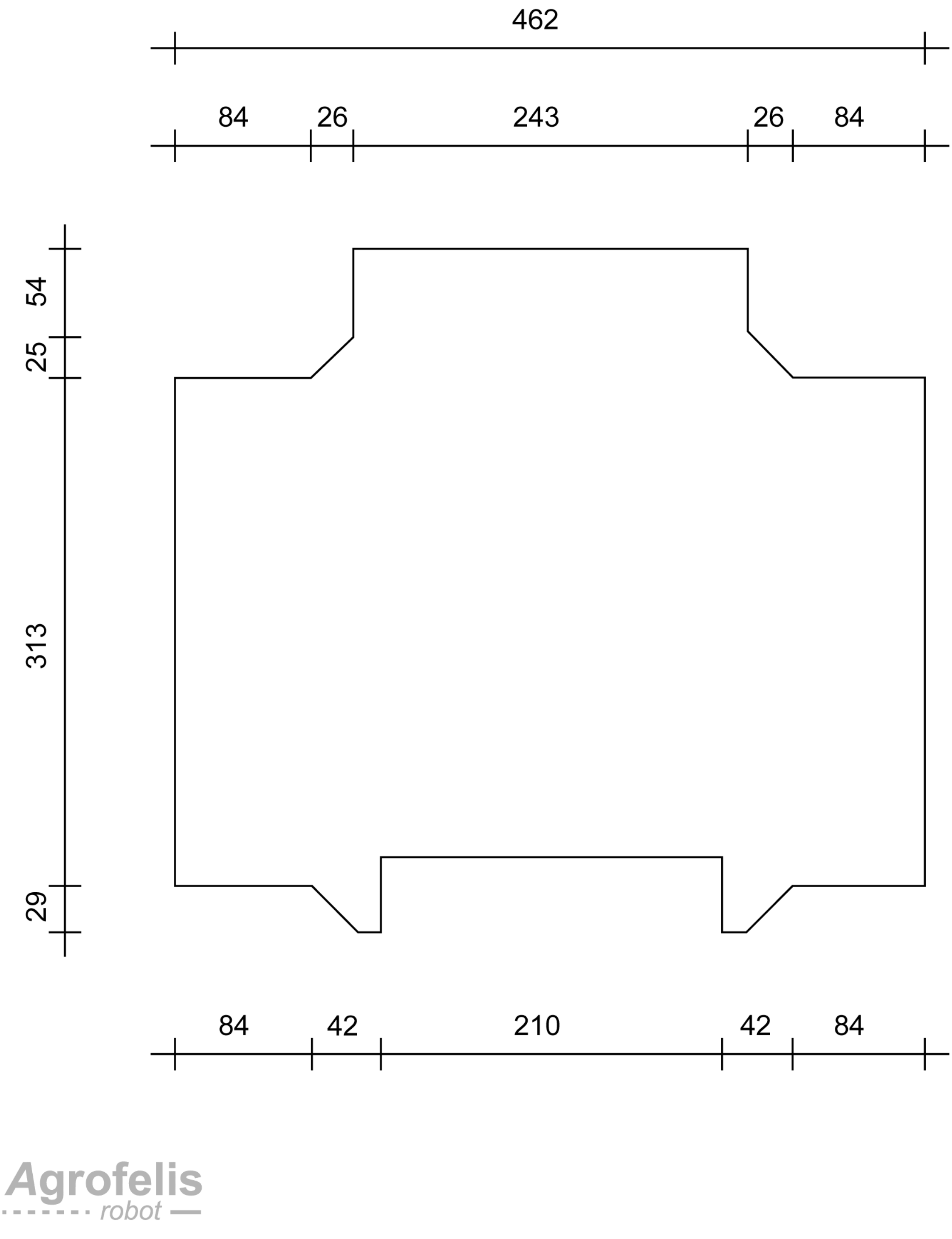


Figure 8: Battery cover 3mm schematic

The top back and bottom back covers were also too large to be produced by our DIY plasma cutter. The silhouette dimensions are annotated in the following schematic.

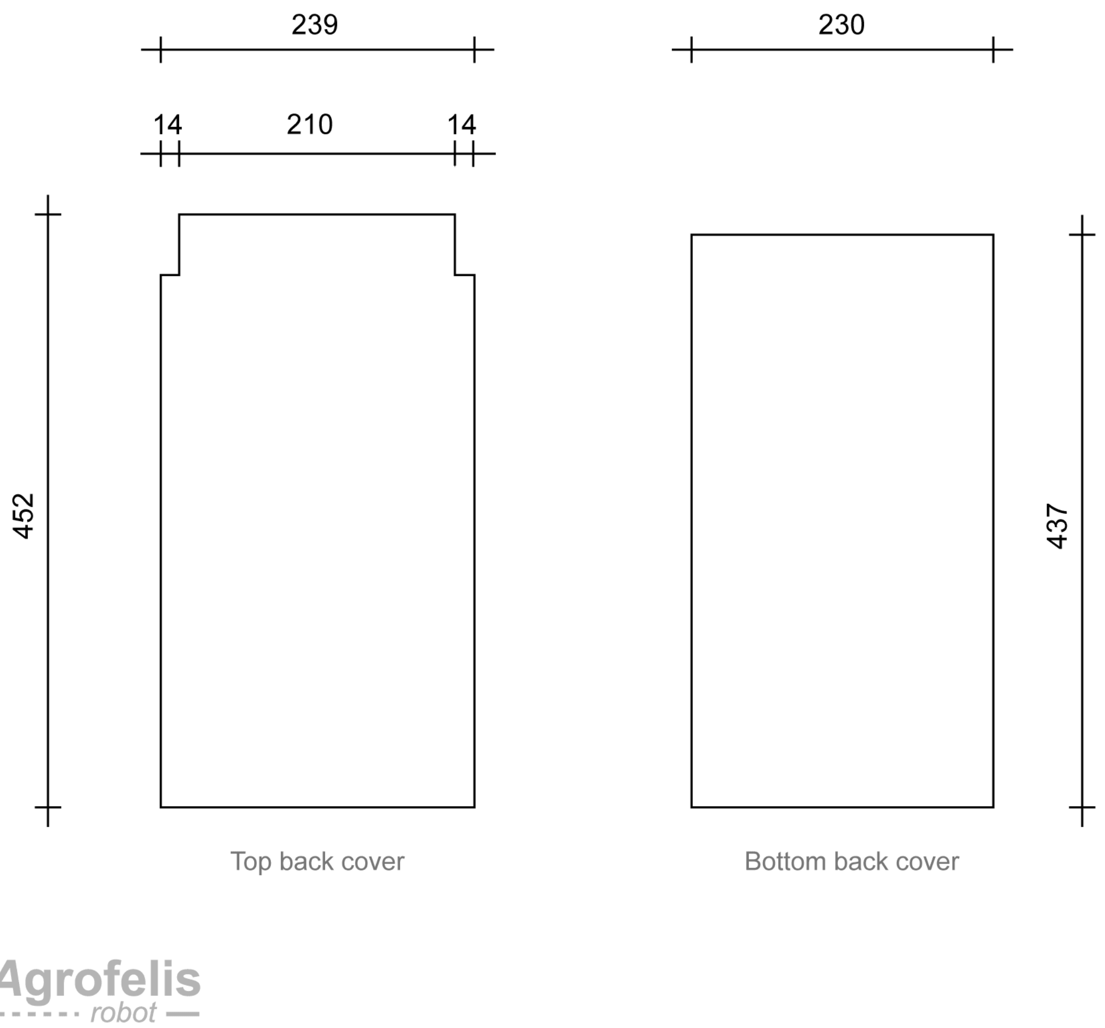


Figure 9: Top bottom back cover

The fabricated details of the battery cover and the top back cover as these are mounted consequently in the vehicle, are showcased by the consequent photo.

Figure 10: Battery cover actual

The fabricated left-side part 1 and 2 covers mounted in the vehicle, are showcased by the following photo.

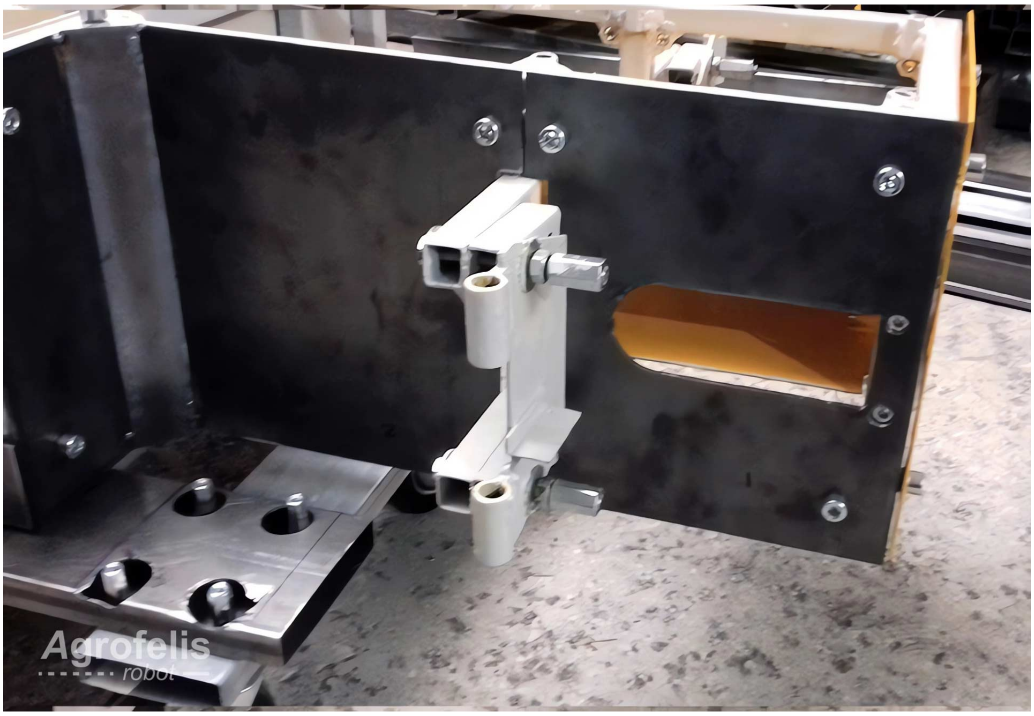


Figure 11: Covers photo a

The next photograph depicts the detail of the back left-side covers. as these change into the battery compartment, specifically parts 1-6.

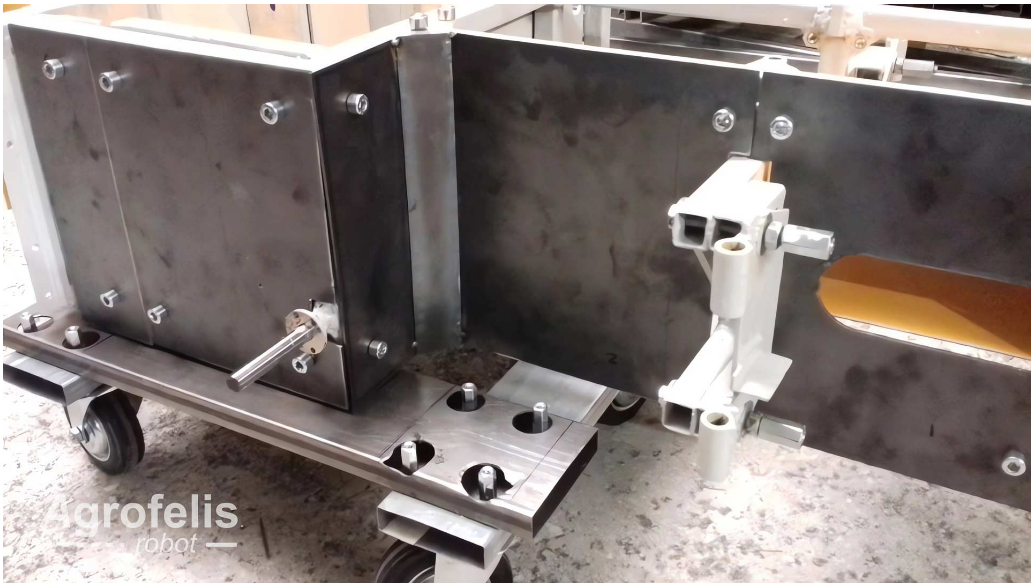


Figure 12: Cover photo b

The following photo snapshots the covers in the process of drying after being coated with primer and orange oil paint.

Figure 13: Covers painted

Covers Material and Indicative Suppliers

The following table lists the individual components employed for manufacturing the Agrofelis frame's protective covers. The index table includes moreover the product URLs, the indicative suppliers, as well as the unit price total amount.

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#1	Black iron metal sheet 1000x2000x3mm	3mm metal sheet	QOOP Metalworks	0.25	73.85	18.50	-
#2	Black iron metal sheet 1000x2000x2mm	2mm metal sheet	QOOP Metalworks	1	49.23	49.23	-
#3	750ml Vitex Metal Primer	Primer	Stereotiki	0	6.50	0.00	Reused from frame material
#4	Orange oil paint 0,75kg	Metal paint	Bousounis	1	9.70	9.70	-
#5	Brushes	Brush	Nova Ceramica	3	1.00	3.00	-
#6	White spirit	White spirit	Rigatos Shop	1	1.50	1.50	-
#7	Paper sheet	Paint paper	Xromagora	0	0.80	0.00	Reused from frame material
#8	40mm x 40mm hinge	Door hinge	Zalonis	1	0.60	0.60	-
Total						**82.53**	

Consequently, we observe that the total manufacturing cost of the Agrofelis protective covers, excluding expenses for shipping, cutting, welding and painting, is approximately **83** euros.

Summary

This document has provided a comprehensive illustration and enumeration of all the vehicle's covers. The design blueprints for the cover parts as well as the plasma-cut source files were organized and indexed. Additionally, the raw materials needed to fabricate the vehicle's protective covers were documented and linked to indicative suppliers. To conclude, an image of the vehicle, positioned vertically on a transferring platform with most of its covers attached, is presented below.

Figure 14: Covers established

End of document

Agrofelis Steering System Design and Fabrication

Documentation

Agrofelis

Document created on 2023-10-09 04:40:31

Abstract

This document delves into the intricacies of the Agrofelis vehicle's steering system. The design rationale, structural elements, feedback mechanisms and the custom PCB board are all presented and documented in detail. The document encompasses source code files, key design metrics, schematics, 3D printed assets, laser-cut NC files and photographs, offering a view of the fabricated components and manufacturing steps in a progressive manner. The steering module of Agrofelis enables it to make a tight 1-meter turn radius and its design minimizes the overall footprint of the vehicle. The document also contains a list of components and indicative suppliers that comprise the bill and material information of the steering module. Finally, the documentation provides an overview of the implemented driver software, its classes, and their relations.

Contents

Introduction

The key design factors of the Agrofelis vehicle's steering system were space minimization, sufficient torque to steer the wheels on uneven terrains, sufficient turning speed, feedback motion sensors for precise wheel movement and monitoring capacities to observe the current drawn by each wheel while turning. While conventional passive systems employ a mechanical solution for the Ackerman steering geometry, the Agrofelis steering system implements the ratios dynamically via software and two independent linear actuators. This approach, although more difficult to implement, results in a more compact footprint, promotes the modular mentality and potentially allows for a wider range of wheel alignment options worth researching.

In the following sections, the various sub-modules utilized within the Agrofelis robot's steering system, are meticulously documented. In particular, the overall schematic is presented and decomposed into the steering plates, linear actuators and their protective covers, the feedback mechanism, custom gears developed using a laser cutter, 3D printed protection covers for the feedback mechanism, the Agrofelis linear actuators steering driver PCB and its associated software.

Steering Module

The following schematic diagram provides an overall view of the steering system.

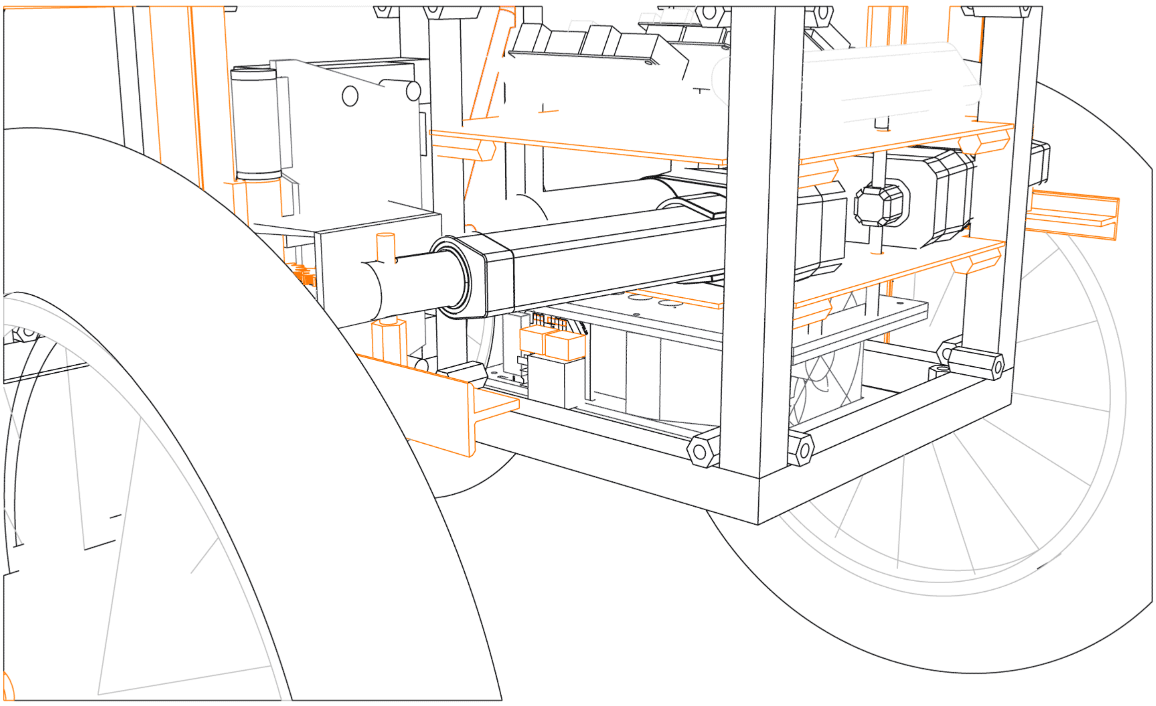


Figure 1: Steering system view

The subsequent view diagram depicts the key sub-elements of the steering system.

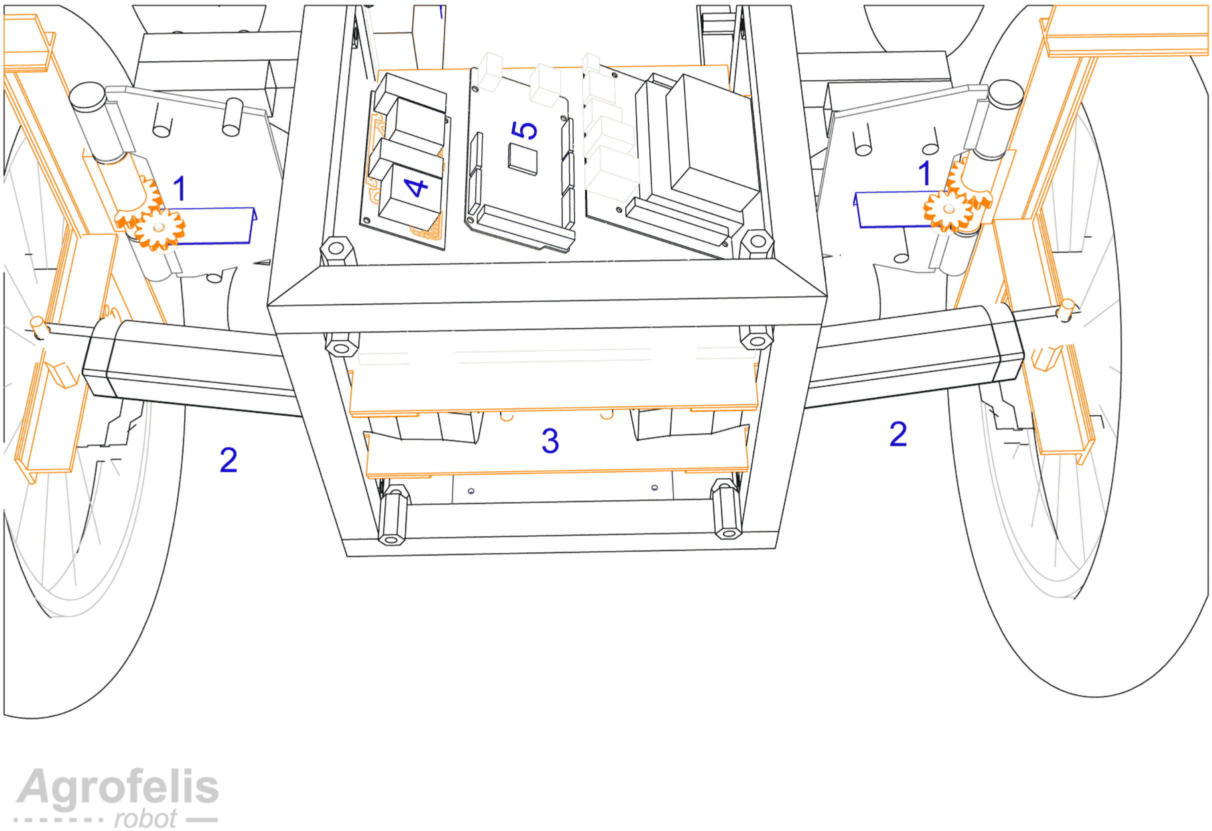


Figure 2: Steering system sub elements

More specifically, the diagram illustrates the following elements:

1. The feedback mechanism, enabling to monitor the actual position of the wheel.
2. The linear actuators mounting on the steering plate and the forks lever.
3. The steering plate that provides fixed points for the linear actuators to turn the wheels.
4. The custom PCB shield housing the actuator drivers, current sensors, and sensor inputs.
5. The Arduino Mega micro-controller responsible for processing the related signals and controlling the steering actuators.

Steering Plates

The steering plates consist of two detachable 2 mm horizontal plates with welded nuts that are mounted onto the vehicle frame through relevant holes made in the frame. The steering plates provide sufficient headroom to enclose the two linear actuators and provide fixed push points via two 6 mm rods piercing the plates vertically. Furthermore, the steering plates create three compartments within the vehicle's frame. The bottom compartment hosting the Agrofelis motors hub driver, the middle one hosting the steering linear actuators and the top compartment hosting the steering micro-controller and the Jetson Nano embedded computer.

The following diagram depicts the described steering plates, annotated with key dimension metrics.

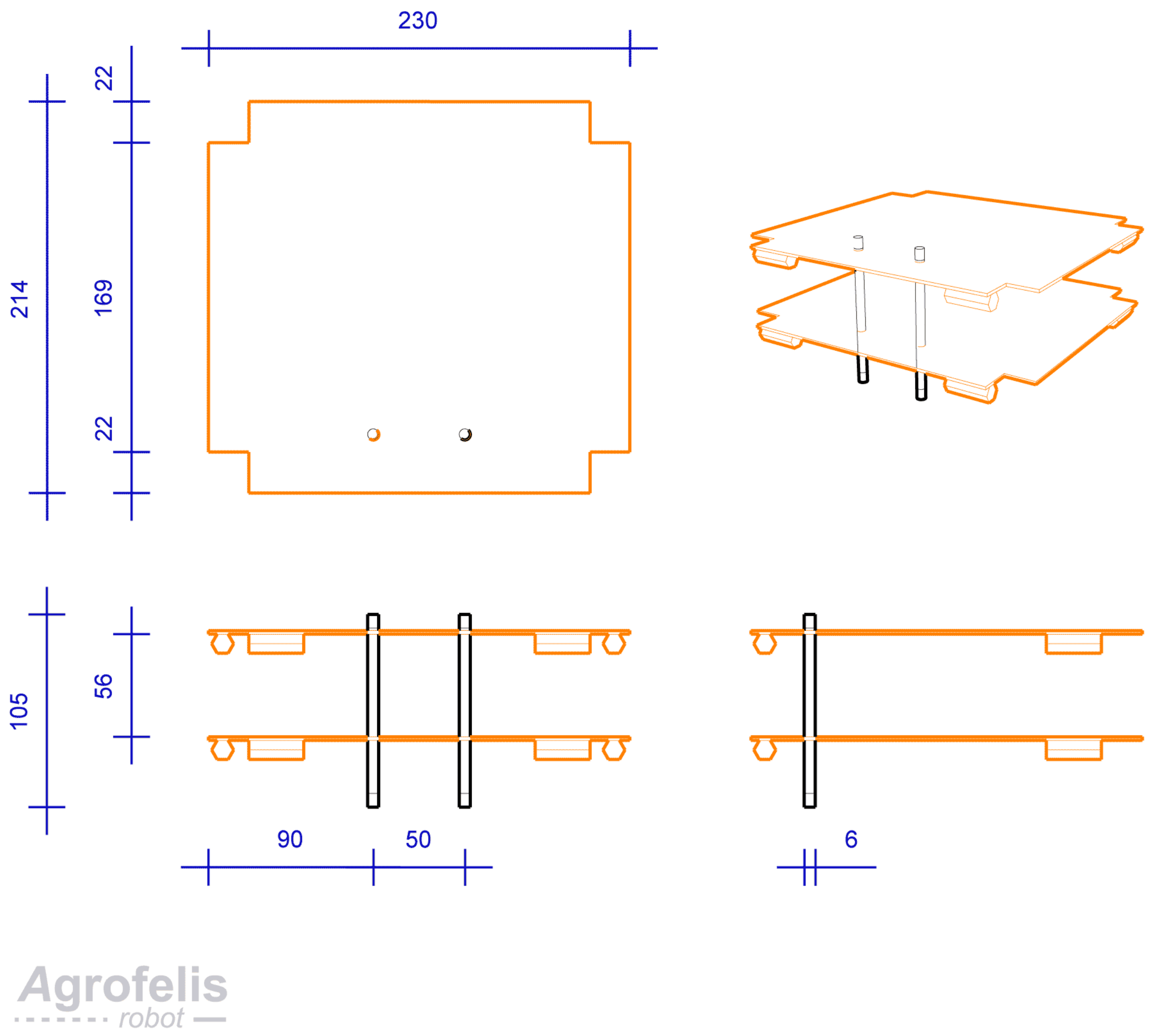


Figure 3: Steering mounting plates diagram

The consequent photo, snapshots the two plates just after these were cut with a grinder.

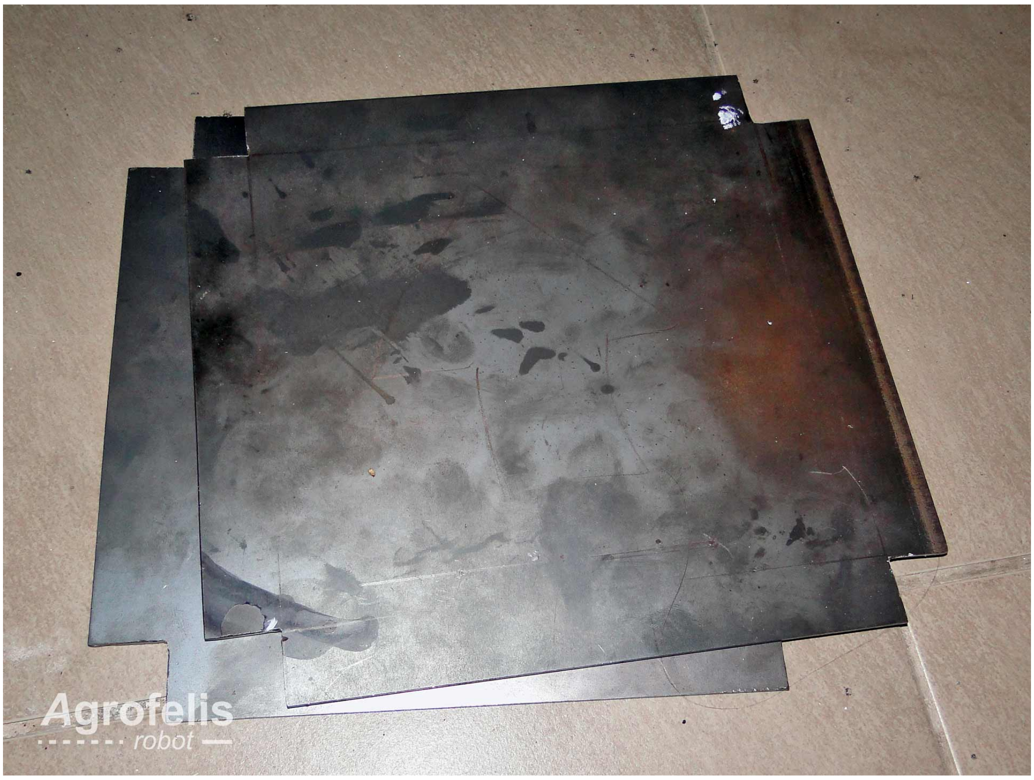


Figure 4: Cut steering plates

The image below illustrates the early stages of the fabrication and how the linear actuators are mounted and positioned in order to rotate the wheels during actuation.

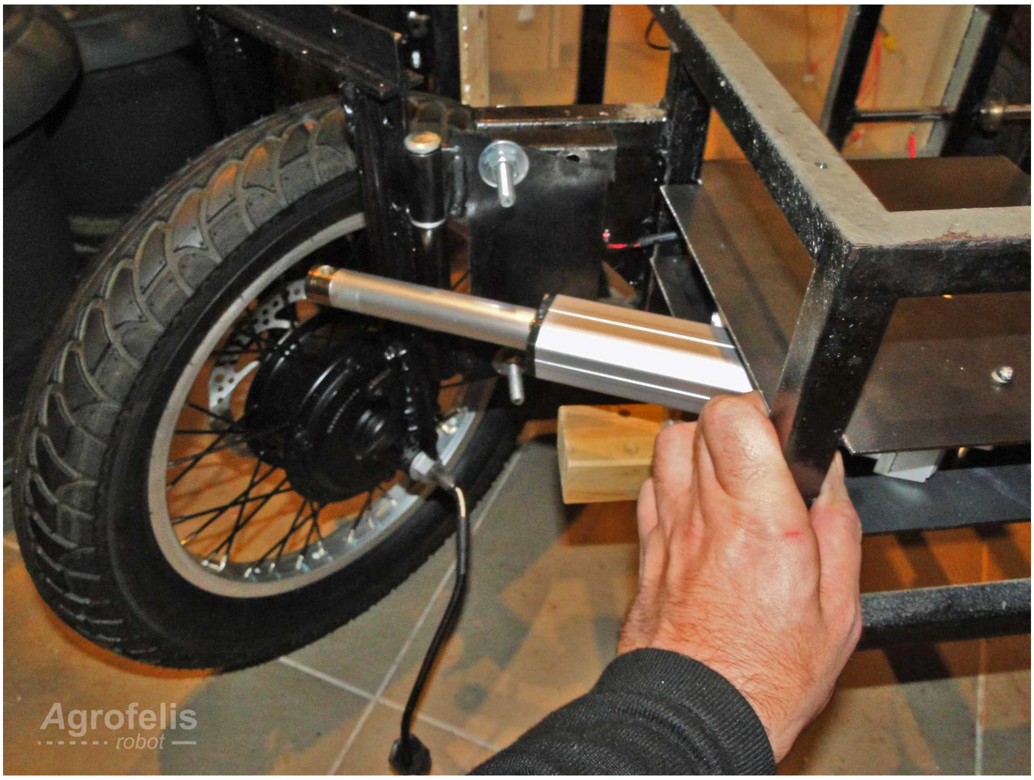


Figure 5: Mounting plates fabrication

The following image shows a close-up of the steering plates and how the linear actuators are mounted using two vertical rods. The vertical rods are extended farther than necessary as they are conveniently used to further secure the Motors hub driver module when the vehicle is resting at a vertical position during maintenance.

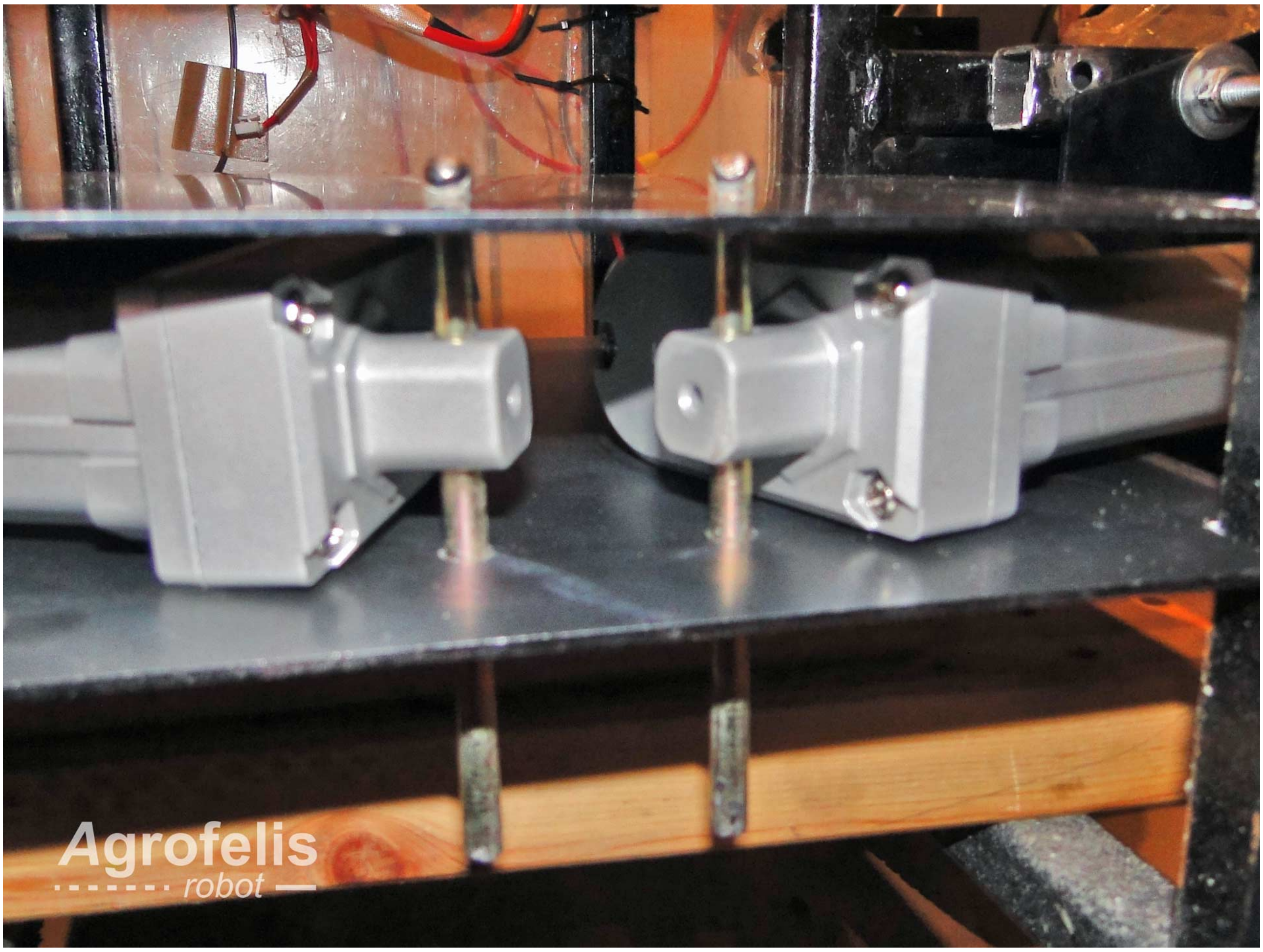


Figure 6: Mounting plates linear actuators attachment

Fork Mounting Points

The linear actuators are attached to the back forks lever using a combination of nut, bolt, washer and ball bearing to minimize friction, as shown in the photograph below.

Figure 7: Ball bearings rollers-1

The assembled mounting point is moreover snapshot-ed by the following photo.

Figure 8: Ball bearings rollers-2

Linear Actuators Protection

Considering that the linear actuators extend from within the vehicle frame, traversing the vehicle's covers and venturing into the external environment, they, along with the frame internals, are susceptible to dust and other undesirable elements. Protective covers were fabricated by cutting and forming an outdoor stretchable waterproof cloth into a cylindrical shape using the following pattern. These covers effectively shield the linear actuators and internal frame components from the environment, while seamlessly accommodating the motion of the actuators.

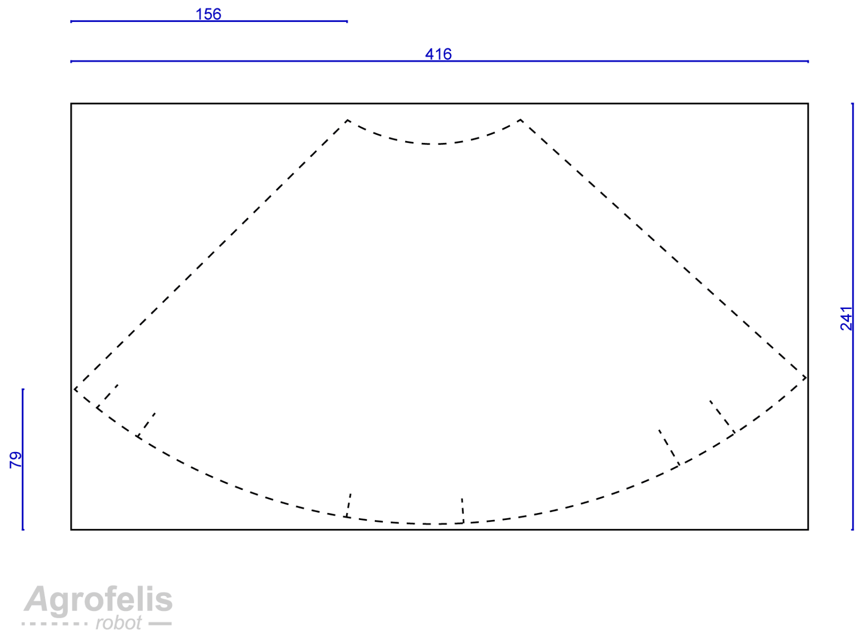


Figure 9: Cloth cover pattern

The waterproof cloth was meticulously cut using a scissor according to the provided pattern, as depicted in the following photo.

Figure 10: Waterproof cloth pattern cut

Sufficient offset has been built into the pattern, which is forgiving to imprecise manual cutting. The cloth piece, rolled into a cylinder with its waterproof side facing outward, is glued to the vehicle's cover plates using standard black electrical tape, as seen by the following photograph.

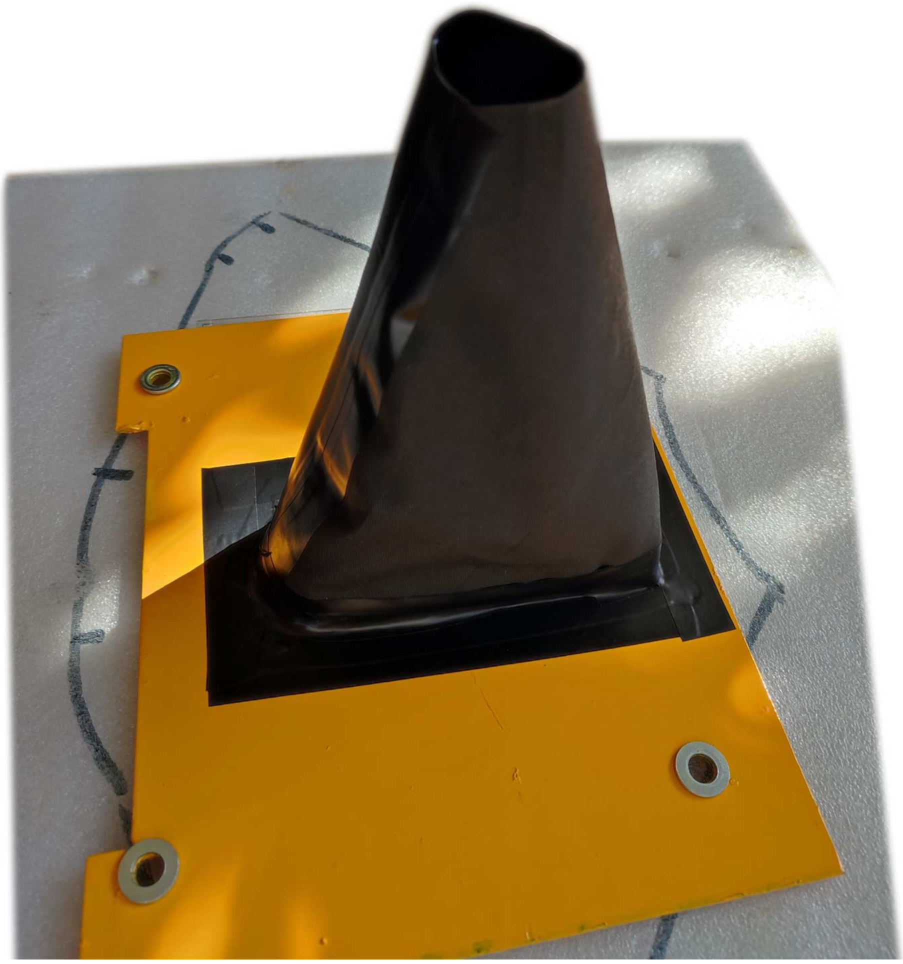


Figure 11: Cloth cover curved and securedl

Feedback Mechanism

If an actuation is not verified, it is quite typical in robots operating in external environments to uncover deviations between the actual movement and the anticipated movement of a system. To address this, the steering system employs various indicator sensors to be able to ensure that movement is accurately verified and detect out-of-the-ordinary metrics, thus enabling the system to signal that something unexpected has happened.

For the motion aspect, two custom gears were designed, one permanently attached to fork's hinge element and the other to a potentiometer attached to the fork's vehicle mounting mechanism. Notably, the feedback sensor is strategically positioned exactly at the rotation point of the fork, compared to the internal rotation point of the linear actuator in order to minimize the translation distance between the measurement and the actual rotation of the wheel.

The schematic view of the feedback mechanism is depicted in the figure below, depicting the two gears and the potentiometer secured on a small corner plate, which is attached to the vehicle's fork mounting mechanism using two screws.

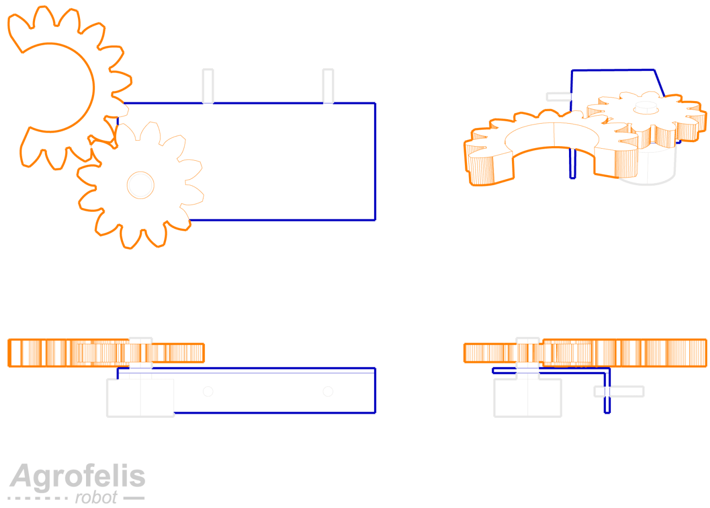


Figure 12: Gears schematic

The gears feedback mechanism dimension metrics are encoded by the following schematic.

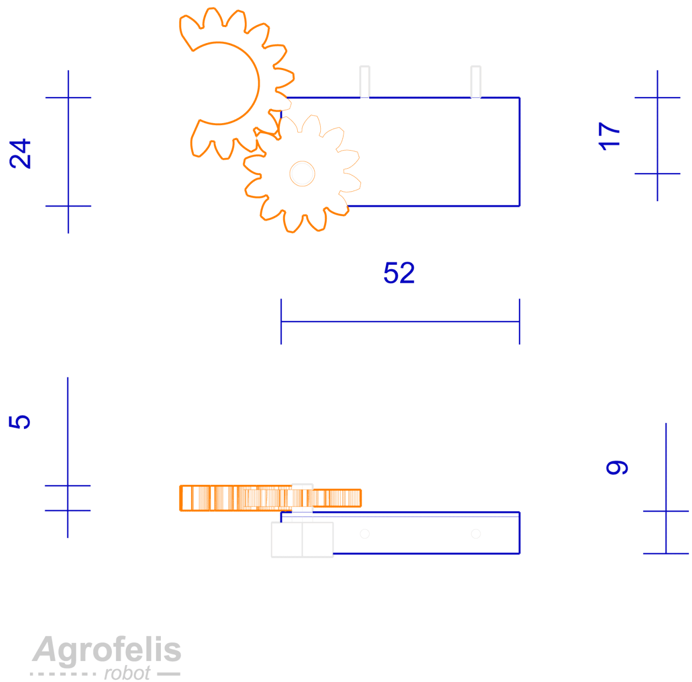


Figure 13: Gears

Multiple gears are being fabricated from a piece of black 2 mm acrylic, chosen for increased strength, using a laser cutter. This fabrication process is captured by the following photo.

Figure 14: Gears actual

A closer view of the potentiometer gear, crafted by stacking and gluing together three 2 mm pieces, is shown in the subsequent photograph.

Figure 15: Gears

The gear design Scalable Vector Graphics (SVG), as well as the corresponding Numerical Control (NC) files driving a low cost laser cutter CNC are available in the following directory:

- assets/laser-cut-feedback-gears

The following files contain respectively the two gear SVG design patterns offset-ed by the size of the laser beam:

- feedback-gear-A-Offset.svg
- feedback-gear-B-Offset.svg

Furthermore, the associated numerical control NC files for driving the CNC machinery are included:

- feedback-gear-A-Offset.nc
- feedback-gear-A-Offset.nc

Finally, the following NC file contains both gears in a single file for convenience:

- feedback-gear-A-and-B.nc

Photos of the fabricated feedback sensors's top and bottom sides, follow.

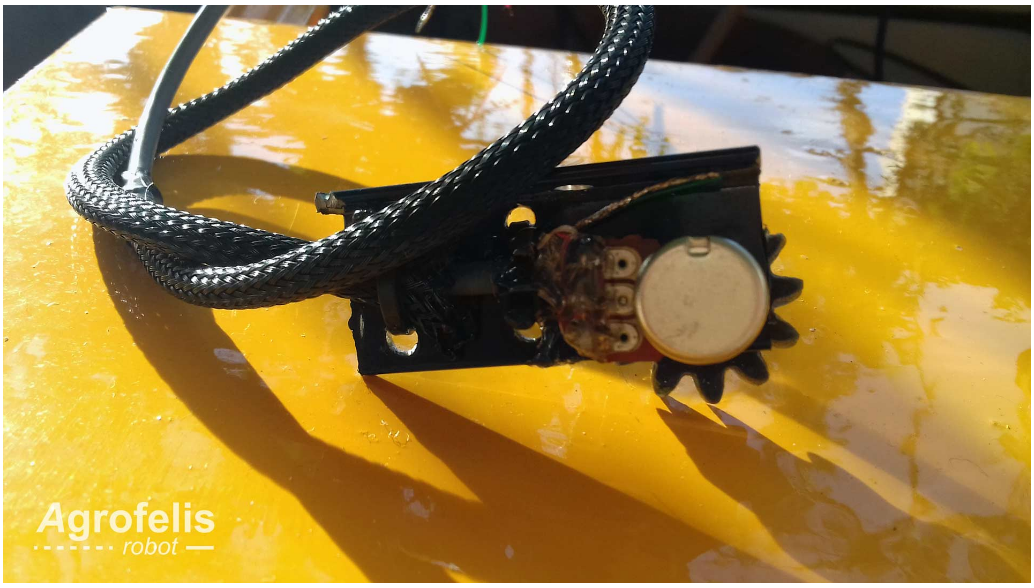


Figure 16: Feedback sensor bottom

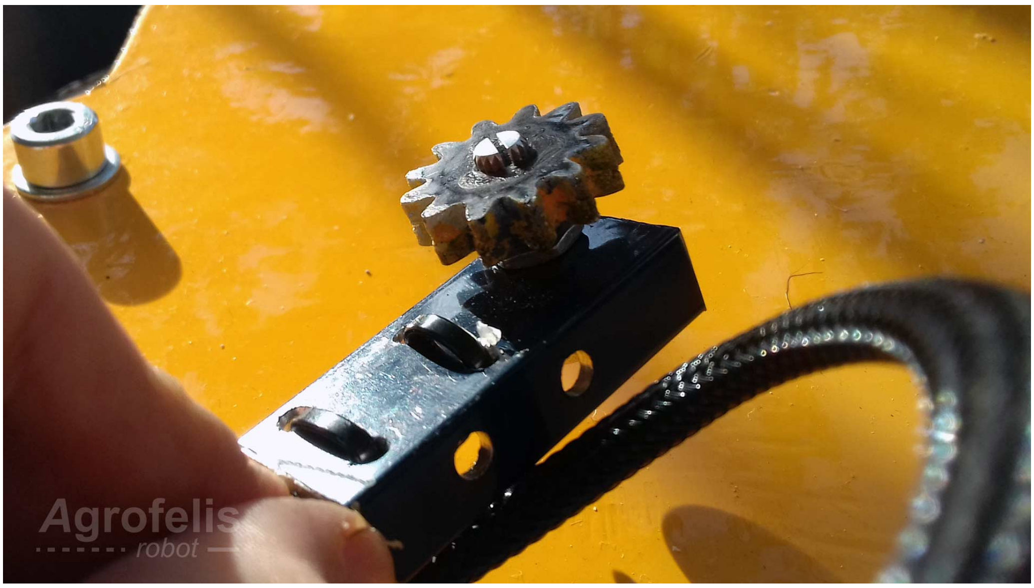


Figure 17: Feadback sensor top

Feedback Mechanism Covers

To safeguard the feedback mechanism against potential interference from plants or other undesired elements that might obstruct the gears, a pair of symmetrical covers was designed and fabricated using a low-cost 3D printer. The protective covers securely attach and detach into the vehicle's fork mounting mechanism using neodymium magnets. The following diagram depicts the cover schematics protecting the feedback sensor.

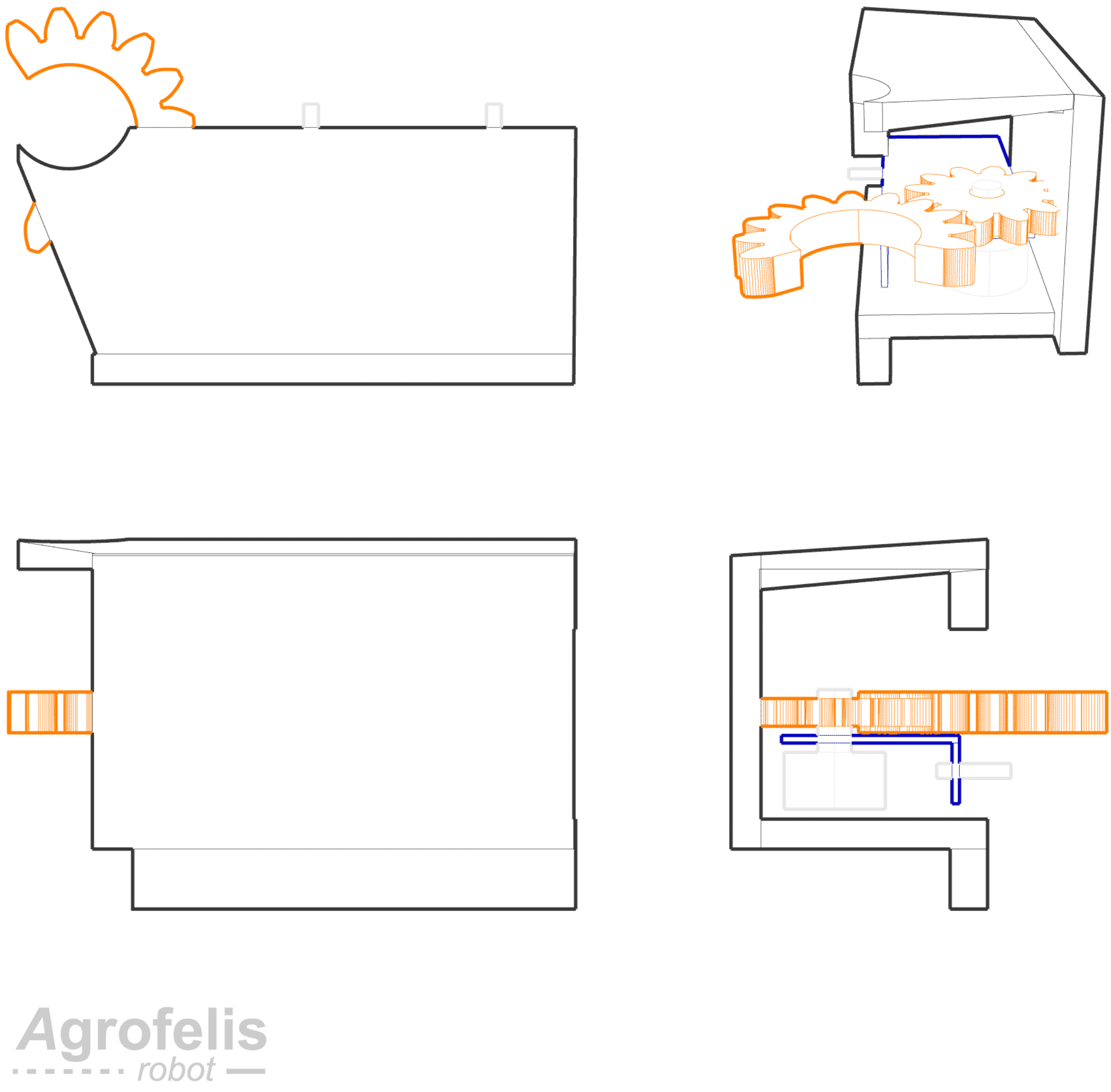


Figure 18: Gears protection cover

The 3D-printed fabricated covers with the magnets incorporated in their structure, can be seen in the following image.

Figure 19: gear-covers-1

The subsequent image portrays the protective covers after being coated with a gray paint for added durability.

Figure 20: gear-covers-2

The following folder contains the left and right protective covers symmetric design stereo-lithography (STL) plans along with their Geometric Code (GCODE) derivatives, driving a 3D printer.

- assets/3d-print-feedback-potensiometer-covers

In particular, the folder contains the following source files:

- potensiometerCoversL.stl
- potensiometerCoversR.stl
- potensiometerCoversL.gcode
- potensiometerCoversR.gcode

The end mechanism without the protective covers is showcased by the following photo.

Figure 21: feedback mechanism actual

The end mechanism with the protective covers can be compared via the following image.

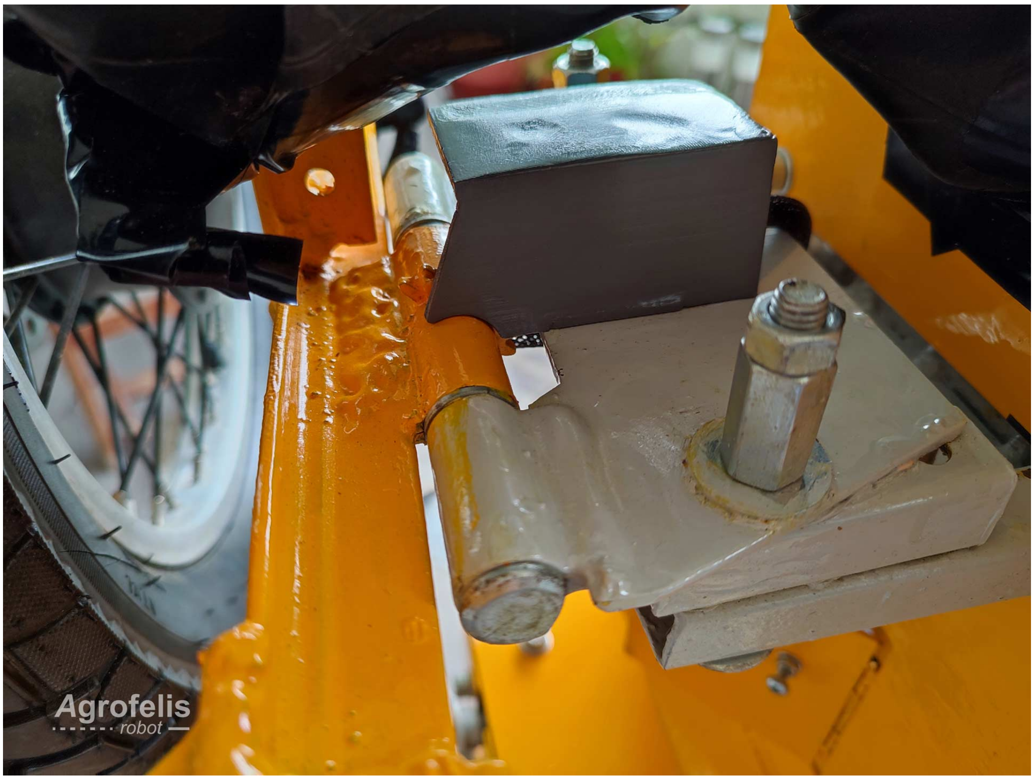


Figure 22: feedback mechanism with covers

Steering PCB Driver

Facilitating the operation of linear actuators, assessing how much they have moved in relation to the applied voltage and friction of the wheel with the ground, as well as monitoring current consumption to detect high or no resistance, a customized board was devised. This board serves the dual purpose of organizing the various electronic components and tidying the cables per actuator and sensor. The shield was designed to be independent of the microcontroller, allowing for example instead of an Arduino Mega an Arduino Mega Pro or an ESP32. Remarkably, the PCB was designed in such a way that it can be cut in half, enabling it to drive two separate linear actuators or similar components within the system.

The designed PCB, outlining the hosted components, input and output pins and their respective functions, is presented below.

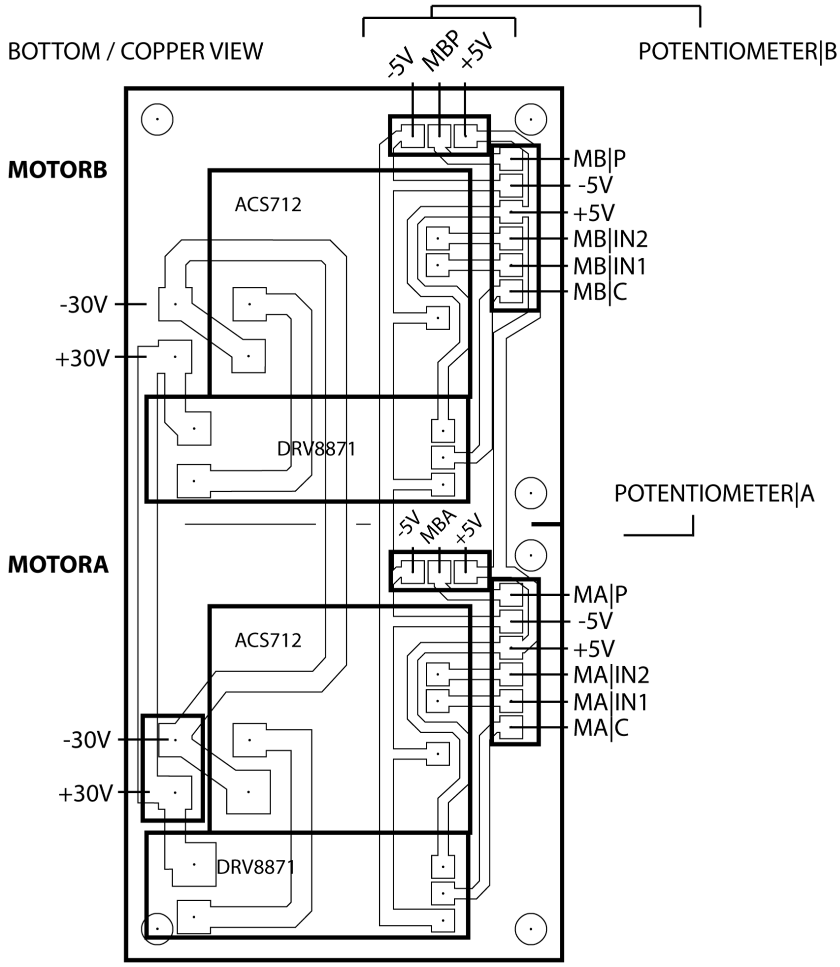


Figure 23: Steering PCB driver schematic

The PCB board scalable vector graphic design plan is located in the following directory:

- driver-board/laser-cut-nc/linear_trails.svg

Its Numerical Control (NC) derivative intended for driving a CNC router, is provided below:

- driver-board/laser-cut-nc/linear_trails.nc

The following figure, encodes the PCB board input/output connected into the Arduino Mega board pins.

PCB Steering driver	Arduino Mega
ANALOGUE IN	A0
-5V	GND
+5V	+5V
DIGITAL/PWM OUT	D13
DIGITAL/PWM OUT	D12
ANALOGUE IN	A1
ANALOGUE IN	A2
-5V	GND
+5V	+5V
DIGITAL/PWM OUT	D11
DIGITAL/PWM OUT	D10
ANALOGUE IN	A3

Figure 24: STEERING_DRIVER_connections

The following figure snapshots the underside (copper side) of the manufactured PCB board.

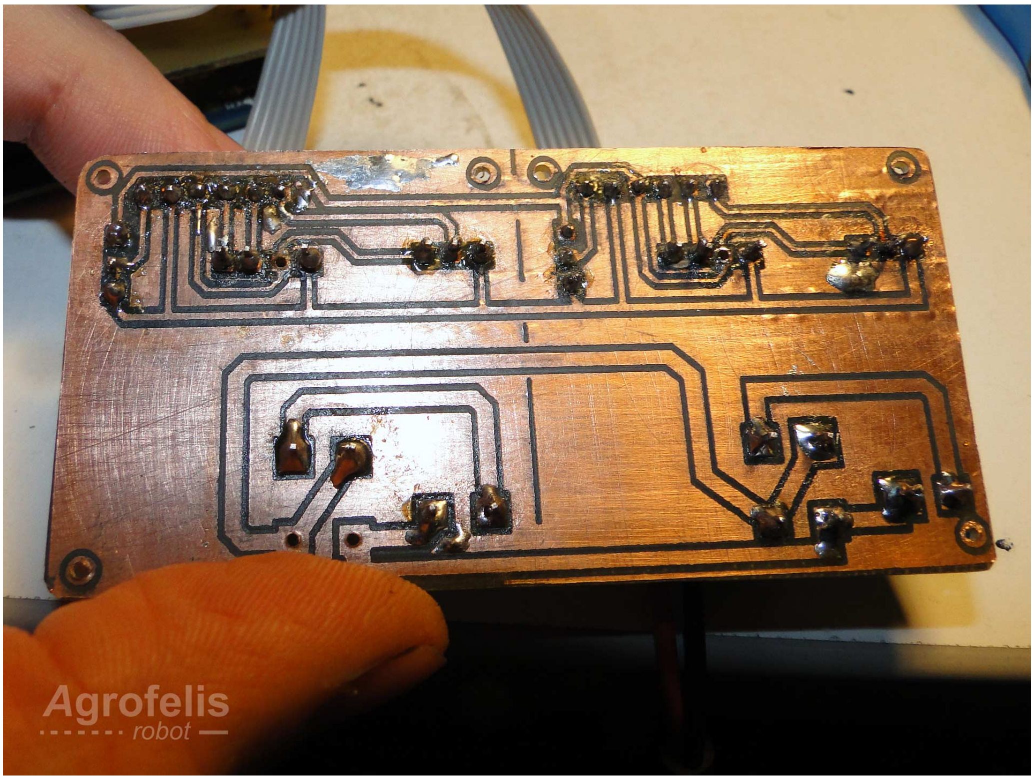


Figure 25: PCB Driver copper side

The consequent figure snapshots the top side of the manufactured PCB board with its components.

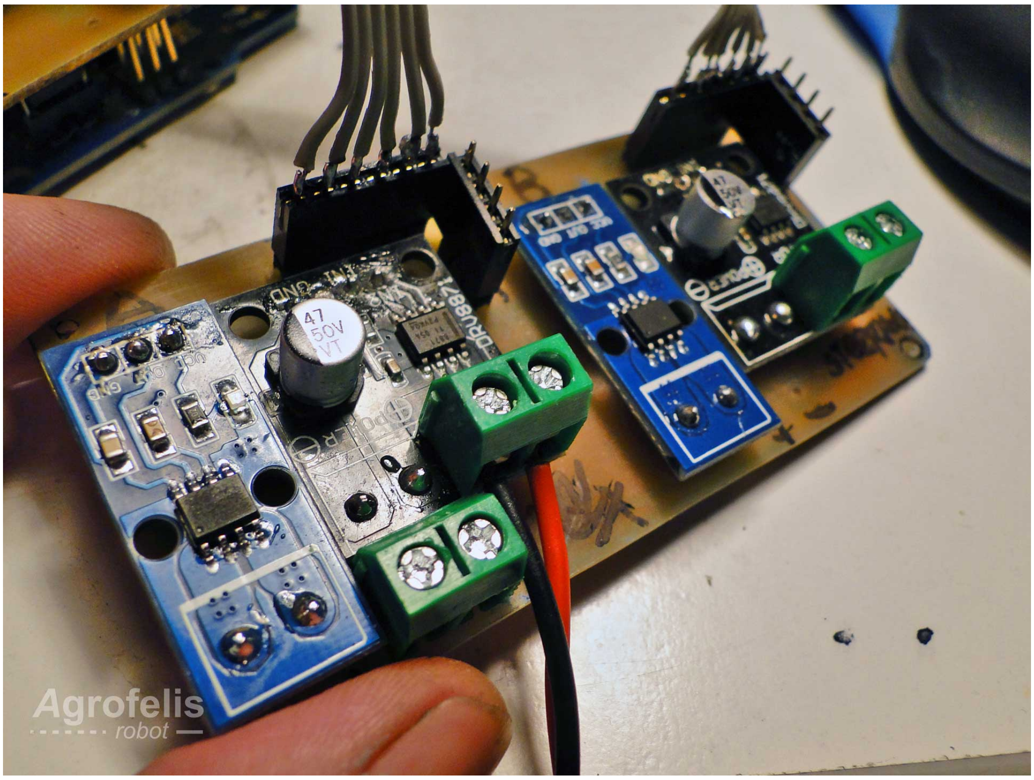


Figure 26: PCB Driver top side

It is noteworthy that although later stages of the project revealed better ways for fabricating PCBs, this particular board was produced using a method involving spray-painting the copper surface of the board, burning the designed pattern using a laser engraver and etching the board in acid. Other PCBs found in the Agrofelis project, have improved this process by curving the board and drilling the holes in a completely computerized manner.

The following figure illustrates a supportive file prepared for cable management and more specifically by printing the related labels, cutting them and gluing them using transparent tape, denoting the cables functionality and/or voltage level.

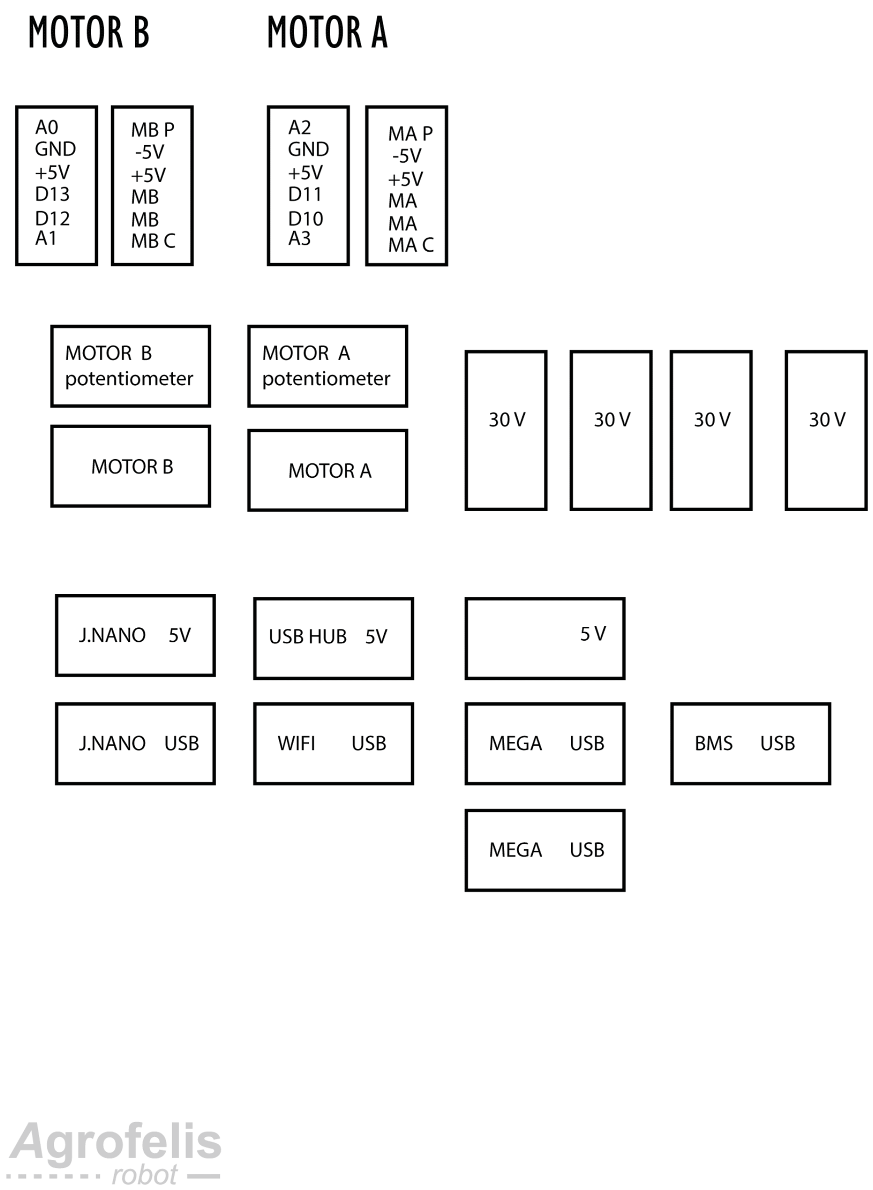


Figure 27: STEERING_DRIVER_CABLES_LABELS

The editable vector file can be accessed here:

- driver-board/STEERING_DRIVER_CABLES_LABELS.pdf

A photo illustrating how these labels have been used to assist the fabrication process is provided.

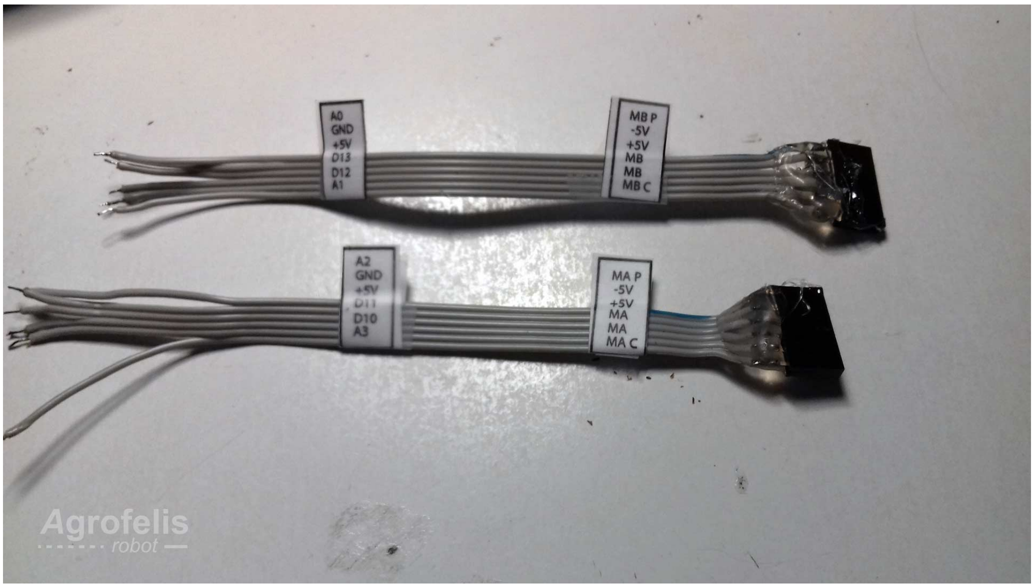


Figure 28: cable labels

The following image highlights the positioning of the PCB shield next to its micro-controller, on the upper side of the steering plate, on the back side of the Agrofelis vehicle frame.

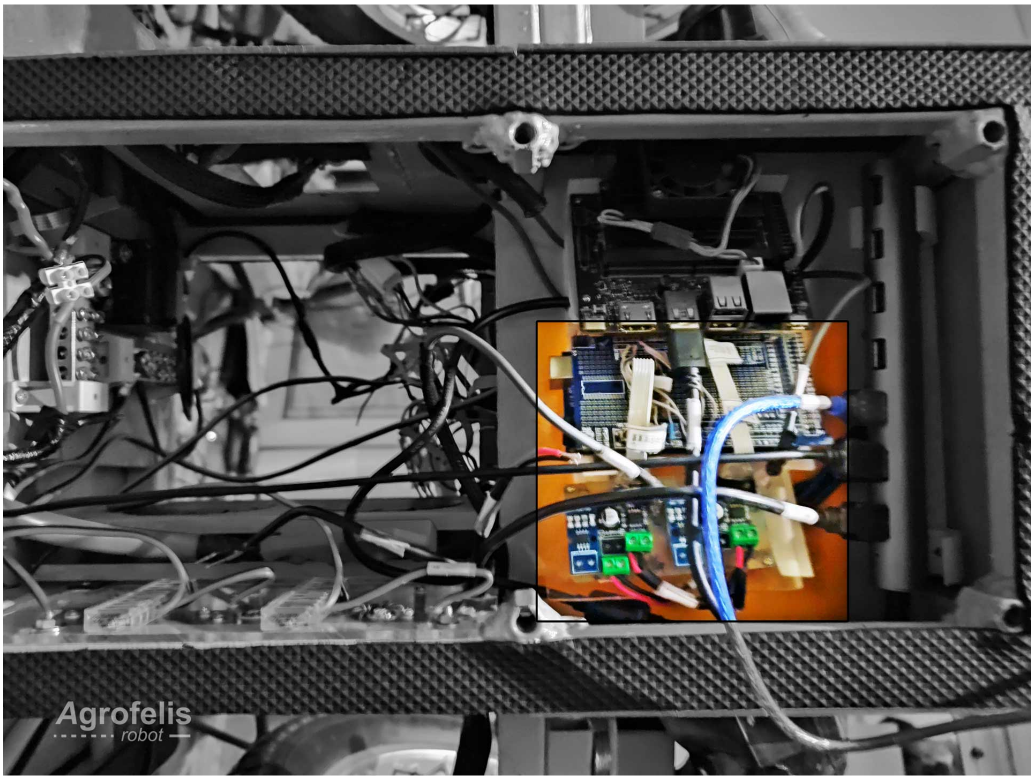


Figure 29: pcb-driver-2

Steering PCB Components

The following table lists the individual components employed for manufacturing the Agrofelis steering controller. The index table includes moreover the product URLs, the indicative suppliers, as well as unit prices and sum totals.

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#1	Copper board	PCB board	GRobotronics	0.25	9.90	2.48	Shared Resource
#2	H-Bridge Brushed DC Motor Driver	Motor Driver	Cableworks	2	6.00	12.00	-
#3	Linear Potentiometer B10K Ohm	Metal potentiometer	Hellas Digital	2	1.24	2.48	-
#4	ACS712 5A Range Hall Current Sensor Module	5A Current sensor	Ali Express	2	1.10	2.20	-
#5	6-wire ribbon cable 120 mm	Ribbon cable 28AWG	GRobotronics	0.25	1.00	0.30	Shared Resource
#6	3 wire cable 350 mm connecting the potentiometer	3 wire cable	Hellas Digital	1	2.60	2.60	-
#7	6-pin header female	Female Pin Header Kit	Nettop	0	9.90	0.00	Shared Resource
#8	3-pin header female	Female Pin Header Kit	Nettop	0	9.90	0.00	Shared Resource
#9	3-pin header male	Male Pin Header Kit	Nettop	0	9.90	0.00	Shared Resource
#10	3-pin header male	Male Pin Header Kit	Nettop	0	9.90	0.00	Shared Resource
#11	Arduino Mega	Arduino Mega	Ali Express	1	10.00	10.00	-
Total						**32.06**	

The total cost to manufacture the Agrofelis steering driver shield, exclusive of shipping and labor cost, totals approximately **32** euros.

Steering Actuators and Structural Components

The following table enumerates the components utilized in the fabrication of Agrofelis steering structural elements. The index table encompasses the product URLs, indicative suppliers, as well as unit prices and sum totals.

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#1	Black iron metal sheet 1000x2000x2mm	2mm metal sheet	QOOP Metalworks	0.25	49.23	12.30	-
#2	8 Nuts 5mm	Nut 5mm	QOOP Metalworks	8	0.10	0.80	-
#3	10 Allen bolts 5mm	Bolt 8mm	QOOP Metalworks	10	0.20	2.00	-
#4	Mini Plane Axial Thrust Ball Bearing F7-17M 7 x 17 x 6mm	Ball bearing	Ali Express	2	1.31	2.62	-
#5	Linear actuator 24V 500N 20mm/s, Stroke 100mm	Linear Actuator	Ali Express	2	36.70	73.40	-
#6	Powerful Round Magnets 5x3mm	Round Magnets	Hellas Digital	4	0.10	0.40	-
#7	Powerful Magnets Block 20X5X3mm	Block magnet	Hellas Digital	2	0.15	0.30	-
#8	Waterproof fabric 1 sqm	Waterproof fabric	Yfasmatakesidis	1	5.00	5.00	-
#9	6 mm rod	6 mm rod	QOOP Metalworks	2	2.00	4.00	-
Total						**100.82**	

The total cost to manufacture the Agrofelis steering structural and actuators components, excluding shipping and labor cost, amounts to approximately **101** euros.

The combined total cost for fabricating the Agrofelis steering structural, actuators, and electronics components is approximately **132** euros.

Steering Driver Software

The Agrofelis software source code developed, which manages the steering system via its actuators and sensors running on an Arduino Mega, containing 23 source code files and 3 supportive files, is referenced in the following directory:

- src/linearSteer

The source code incorporates an INO file that initializes the application, along with a series of H and CPP files encoding the declarations and implementations of the classes of the application.

The project uses an Arduino Mega and a handful of components to sense and control two linear actuators, establishing the steering system. The module utilizes the serial interface to share the internal state of the components, as well as to control them.

The module consists of a custom PCB that hosts two current sensors, two motor drivers and two inlets for two potentiometers that are used as feedback sensors to read out the steering angle of the wheels. The software enables individual as well as synchronized control of each linear actuator based on the Ackerman geometry and the physical orientation of the vehicle. The valid ratios of the wheels are measured in fine steps and persisted in an interpolated association map.

The module status facilitates remote configuration, so the linear actuators are driven to reach the minimum and maximal points in order to dynamically derive the center and the bounds of applicable movement. Furthermore, the minimum voltage required to achieve a movement can be derived, as the lowest applicable speed.

The module provides an interface to make both linear actuators seek and reach the desired position. The application implements the functionality so that the linear actuators are operated asynchronously, moving the motors at varying speeds to meet Ackerman geometry based on the observed resistance and the required distance to cover respectively.

Additionally, the software establishes the braking system of the vehicle by driving two servos linked to the disc brakes.

Application Structure

This Agrofelis steering and braking software adheres to a common baseline pattern that has been established in nearly all Agrofelis modules. This baseline establishes a context class that is passed to practically all classes as a common ground, enabling instances to exchange information when necessary. The second baseline pattern established refers to the frequency of execution, providing the facilities to trigger functionalities at the desired intervals. A gyroscope, for example, may need to be triggered far more frequently than a GPS or potentiometer sensor. As a bootstrap template, the software provide 6 different frequencies ranging from 50 milliseconds to 5 second intervals. Using this approach, delays blocking the execution are avoided and the different calls can be organized based on their responsiveness requirements.

The software encodes easy to follow concrete implementations such as current sensors and brake(s), resulting in a one-to-one mapping between the physical element and its respective software counterpart.

The following table indexes and summarizes the implemented classes of the Agrofelis steering and braking controller.

Class	Description
linearSteer.ino	Boots the application, initialises the top classes and encodes the triggering frequencies of various functional elements.
Context	Provides a common ground for sharing information and encodes the triggering frequencies, helpful functions and a unique identifier of the model.
Invoker	Tracks the execution frequencies so these are called at the right time.

Class	Description
Brake	Object representing a wheel brake actuating a servo motor. The object can be initialised with a limited target range, as much as to lift the brake. The class was used with a *TIANKONGRC RDS-8120 20KG ROBOT DIGITAL SERVO*. The class can be instantiated by providing the connected GPIO, the desired range to actuate from the applicable (0-180), which is then mapped to a convenient range of 0 to 100.
Brakes	The class can drive two or more brakes objects simultaneously.
Sensor	Base class wrapping the functions conveying a sensor. The class reads an analogue port when the apply function is being triggered. The class maintains a gated smoothing read out of the sensor by comparing the previous mean with the current read value. Moreover, when a movement is detected based on the absolute difference of the first derivative, a boolean flag is maintained. Lastly, it prints out the object's internal state on print(), reflecting the sensor's port, smoothed value, un-smoothed sensor value and whether or not the sensor is detecting a movement.
SensorCurrent	Class extending the *Sensor class* implementing the specialties of a current sensor. The class translates raw sensor values to amperage. Moreover, because the current sensor reads rapid current spikes that can be missed, the class maintains a decaying max read value that is renewed based on the maximum observed value within a time window.
LinearActuator	The class implements an object to control a linear actuator via a [DRV8871 H-Bridge Brushed DC Motor Driver] component. The class is instantiated with the board port mappings, enabling its re-usability. The first two constructor parameters map the control pins for the direction and the speed of the [DRV8871 H-Bridge Brushed DC Motor Driver] using two pulse width modulation (PWM) ports. Next, the GPIO of the analogue [LinearActuator Potentiometer B10K Ohm] and the analogue [ACS712 5A Range Hall Current Sensor Module] sensors are provided. The module operates based on eight states dictating its function, starting with state zero. In states one and two, the minimum and maximum potentiometer bounds are identified. In state three, the minimum throttle leading to a movement is derived. State four is entered when the module reaches its objective position. In state five, the object seeks to reach the target requested position. States six and seven correspond to erroneous states, such when an actuation is expected but not detected or when the sensor value reads values close to its physical limits. Furthermore, the applicable bounds can be persisted, so these do not have to be re-resolved when booting the Agrofelis vehicle.
Interpolate	Class for interpolating a value based on an input/output mapping pair of values. The interpolation object enables to map an input non-linearly across an input range and linearly within its sub-bounds. The class is employed by initializing it with measurement mapping references such that the Ackerman geometry is followed based on the physical orientation, and raw potentiometer values are recorded by performing incremental movement to both wheels of the vehicle.
SteeringDriver	The class contains the linear actuator references, their Ackerman mapping steps and the means to interpolate their ratios from a -100 to 100 positioning range. The object enables to change the state of the system to seek its movement bounds and minimum voltage leading to a movement. Furthermore, the class can dynamically derive and apply more voltage if the expected movement has not been observed, as well as fade in or fade out the voltage depending on the elapsed time, the progress of the distance requested to accomplish and its difference with its counterpart actuator.
SerialCommandParser	Base class for monitoring and parsing the serial interface data. The class defines the function parsing compact commands of the form <1|1>, where the first parameter corresponds to the applicable action number and the second is an integer value used by the related action.
SteeringController	The *steeringController* extends the *SerialCommandParser* and defines the applicable commands that drive the actuators. Furthermore, the class reflects the internal state of the brakes, the linear actuators and their sensors, so that other nodes in the system are aware of their status.

Furthermore, the repository includes supporting files that were used while measuring and adjusting the left and right linear actuators to achieve an end-to-end Ackerman geometry. The process studies and accounts for the non-linearity characteristics of potentiometers, digital-to-analog converters (DAC), linear actuators and subtle construction accumulative variations in the following directory:

- src/linearSteer/data.modeling

Each steering wheel was rotated to find how much deviation the other wheel requires, for all wheels directions to converge to the same point, in order to match the Ackerman geometry. The following photo depicts how this was performed, for each side of the vehicle and for various rotational degrees increments, using a three strings.

Figure 30: Ackerman and wheels manual adjustment

The file *data.modeling.R* was developed in the R language to study and reflect the end-to-end differences between the left and right sensors and actuators.

The following plot visualizes the raw sensor value differences that must be applied between the left and right sensors in order to physically match the Ackerman geometry when steering from hard left to hard right in constant steps.

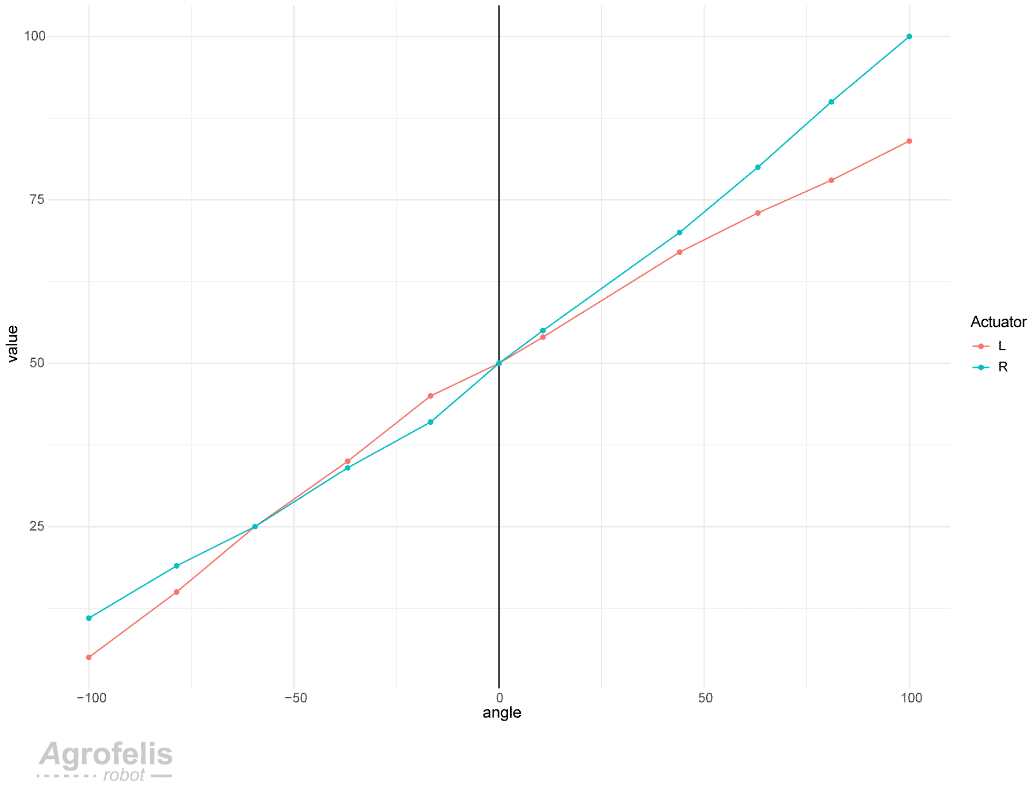


Figure 31: End to end Ackerman geometry differences between the Left and Right input sensors

The steering application runtime information and its modules can also be accessed and controlled via the Agrofelis Unificator software, which is able to unify multiple Agrofelis modules connected from different interfaces (Serial, WiFi, Websockets, USB). Lightweight single page web applications can easily map, bind and monitor the internal state of the steering actuators and their sensors, as seen by the following screenshot.

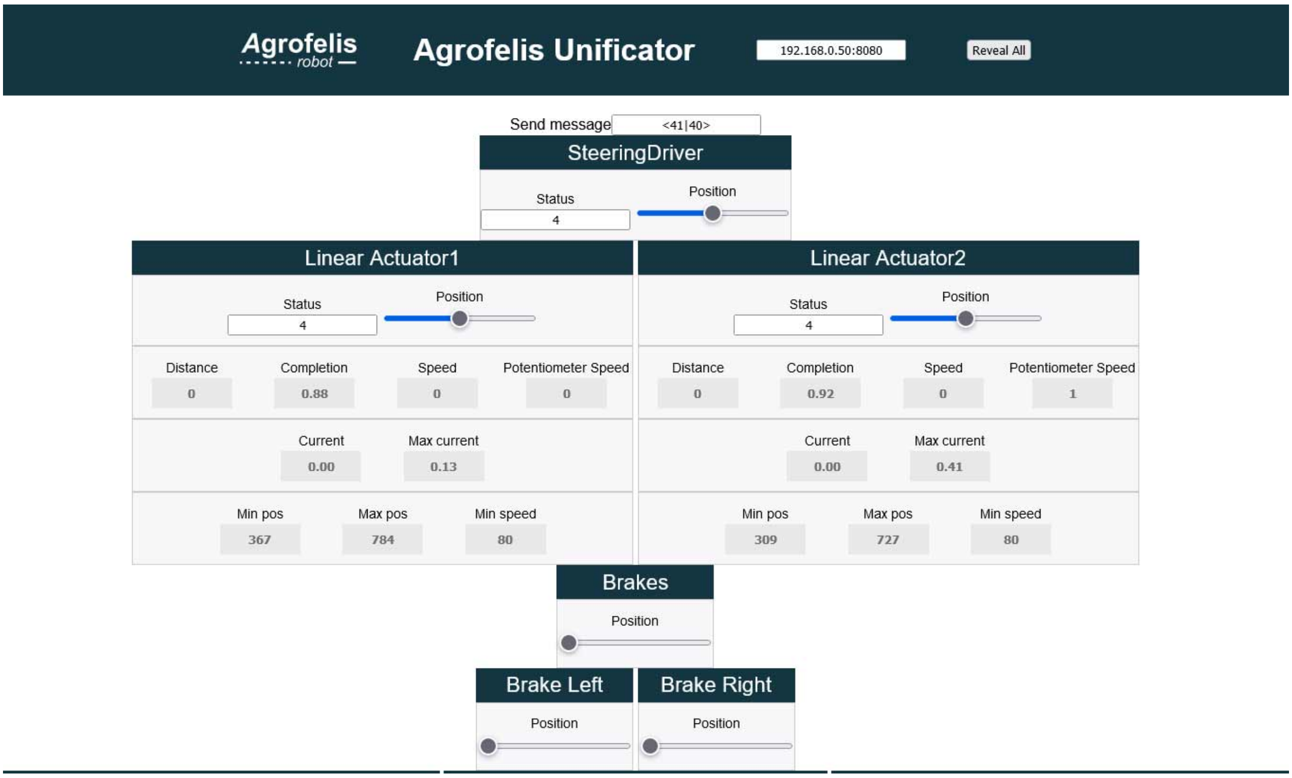


Figure 32: Steering - Agrofelis Unificator

The Agrofelis Unificator software is documented in the related chapter of the Agrofelis documentation.

Summary

The details of this important mobility module of the Agrofelis robot have been documented. All source code files, schematics, numerical control files and patterns involved in the fabrication have been presented, along with photographic material demonstrating the manufacturing progress. The list of components, raw materials, indicative suppliers and cost information that will aid in the reproducibility of the overall steering system has been provided in an organized manner. References to the Agrofelis steering system application source code running on the microcontroller, have been referenced with descriptive information per class, offering a quick overview of the implemented functionality's location. Approaches for bridging the theoretical perfect and the actual were introduced, using practical means such as recording, data visualization and statistics. The documentation concludes by hinting how the steering module fits in the overall design from a software point of view, how it can be accessed and how all modules can communicate, extended and appended on demand.

End of document

Agrofelis Motors Hub Driver Design and Fabrication

Documentation

Agrofelis

Document created on 2023-10-09 04:48:54

Abstract

This document delves into the manufacturing and functional intricacies of a composite module tailored for controlling and sensing a pair of in-wheel motor hubs digitally, over the air. The documentation decomposes the different elements involved into sub-modules, into their sub elements in an organized and progressive manner. A detailed exposition of each component's rationale and its seamless integration with counterparts is provided, bolstered by design plans and photographic evidence of the actual implementation. The document offers a roadmap through the Agrofelis repository, elucidating the source file locations and the production processes underpinning the manufacturing of the Agrofelis Motors Hub Driver. The document presents the structural elements of the unit, the three type of PCB sub-components, the software running on the micro-controller, key tools employed in the manufacturing process and ends with a compendium of indicative suppliers to purchase the different parts.

Contents

Motors Hub Driver

The Agrofelis Motors Hub Driver module's purpose is to digitally control over the air, a pair of motors via two drivers, to monitor their thermal, current and positional indicators as well as to guide the air flow cooling the electronic components, to actuate their power, speed and direction. The module is composed by structural elements, PCB boards separating the different functionalities into simpler standalone sub modules and the software running on the micro controller.

Two such modules are employed in the Agrofelis robot, to achieve four wheel drive and precision control. The following figure illustrates the schematics of the overall module.

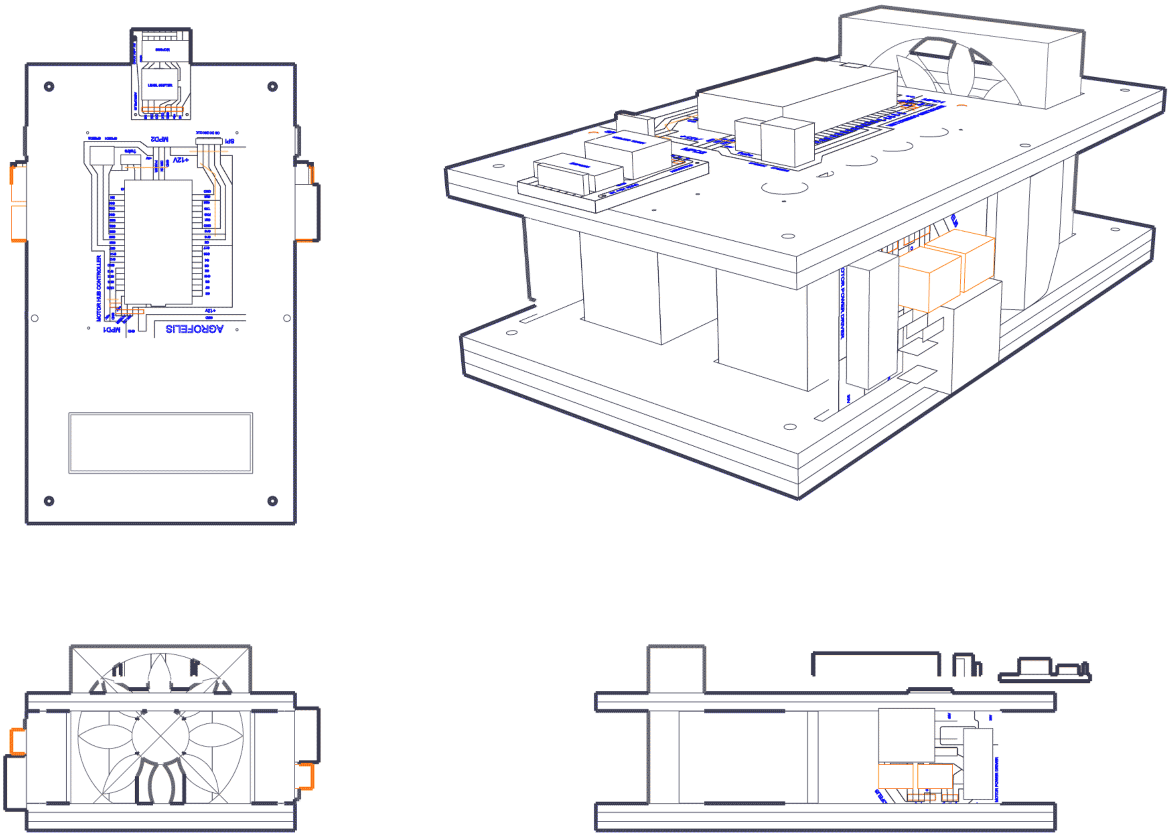


Figure 1: Views and projections of the complete motor hub driver module

Find below a photo of the implemented module, positioned within the front and the back enclosures of the vehicle.

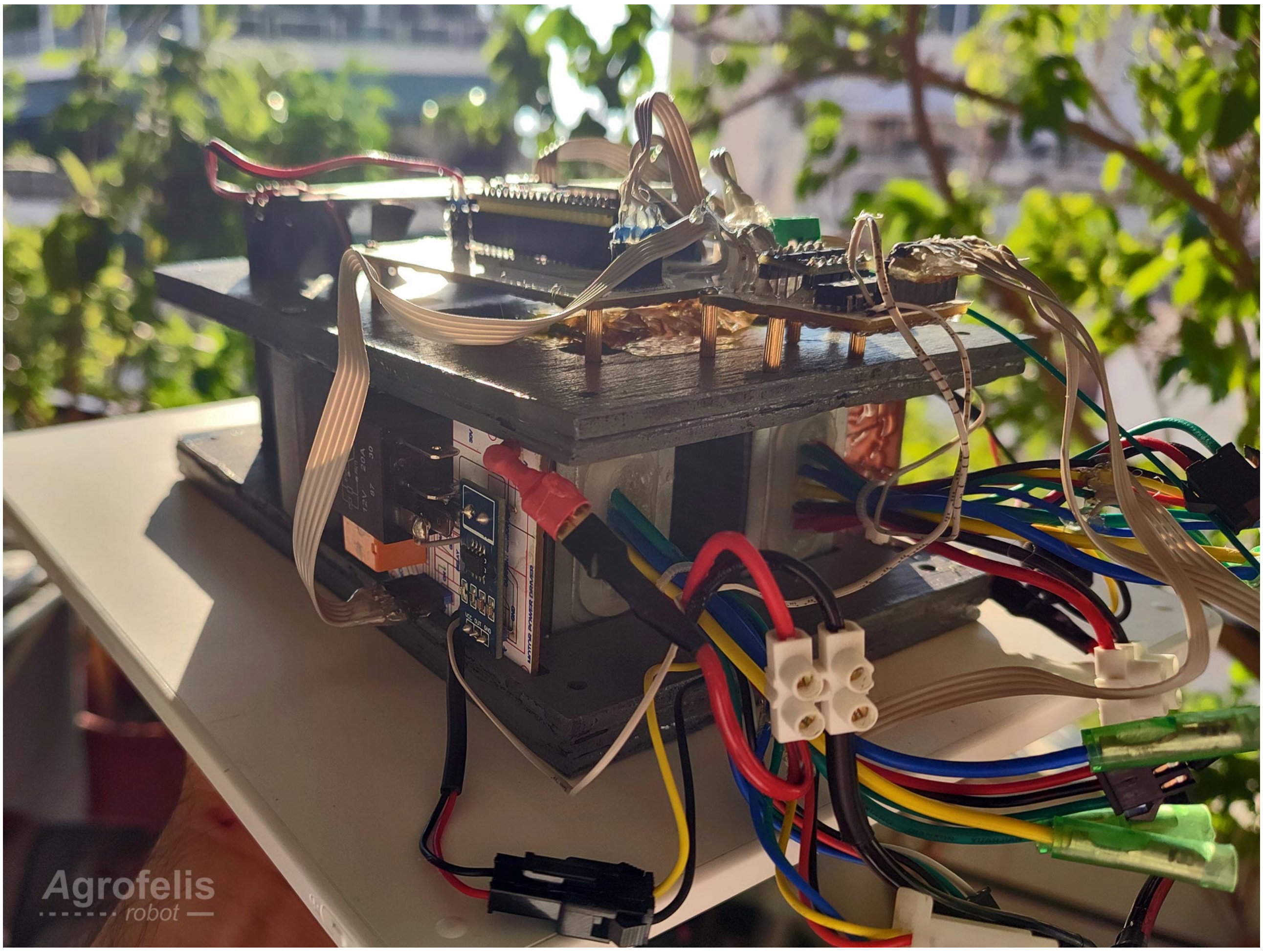


Figure 2: Actual implementation of the motors hub driver module

In the following sections the structural and electronics sub-component of the unit, are documented.

Structural component

This component of the Agrofelis Motors hub driver, deals with the structural elements of the composite module. The structural component is formed by two parts enclosing and mounting the related sub elements. Moreover the structural component serves for guiding the air flow to efficiently cool down the electronics during their operation. The structure body, is composed of layers of ply-wood and 3d printed air fins, glued and painted.

The individual elements forming the structural body are illustrated by the following figure.

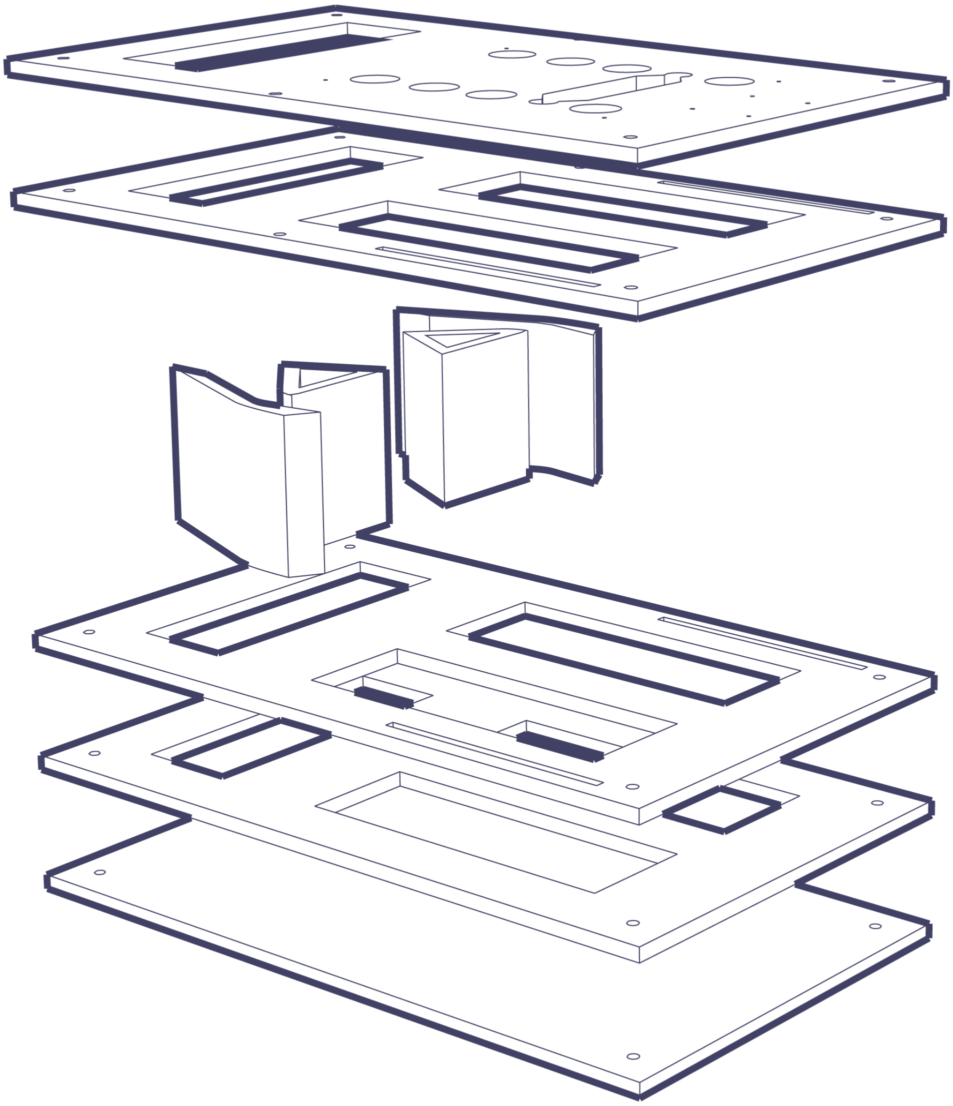


Figure 3: Exploded view of the structural elements, fabricated via laser cutting and 3d printing

The top part of the structural body, creates sockets to host two temperature sensors, sockets to host the two power modules vertically, sockets to attach the analog drivers, as well as holes indicating exactly where the PCB boards are mounted and a socket for an 80 mm fan.

The following photos showcase the top and bottom parts of the structure, manufactured using a low end CNC, equipped with a laser.

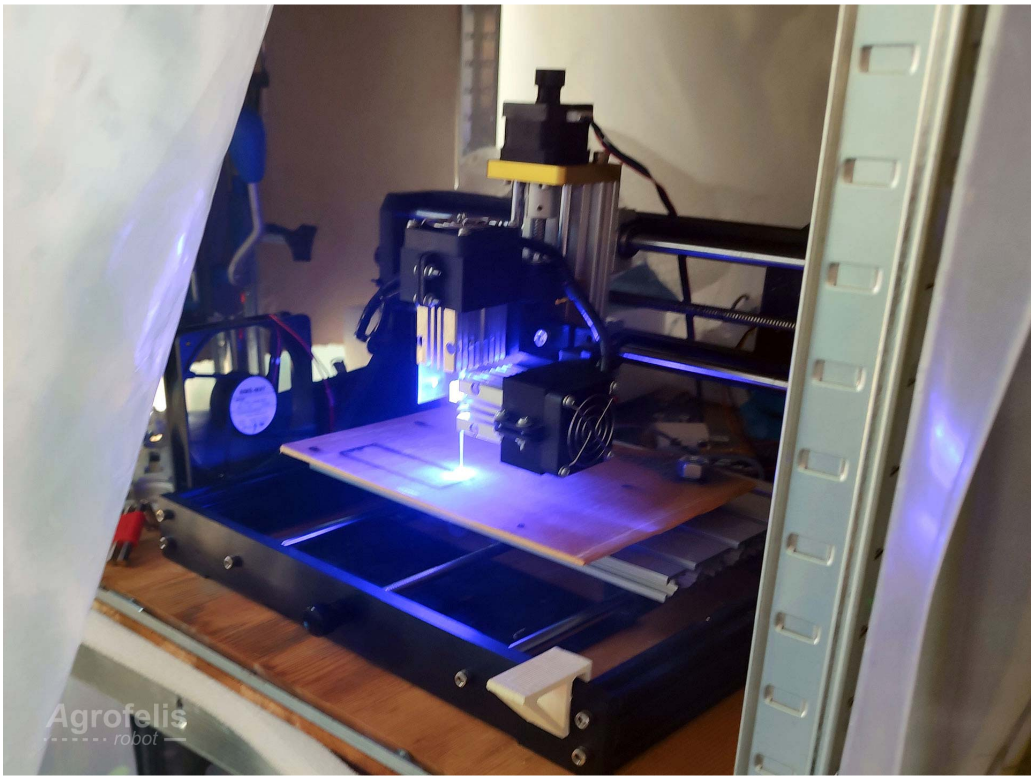


Figure 4: A low cost CNC equipped with a laser, cutting one structural element / layer from a 4 mm plywood

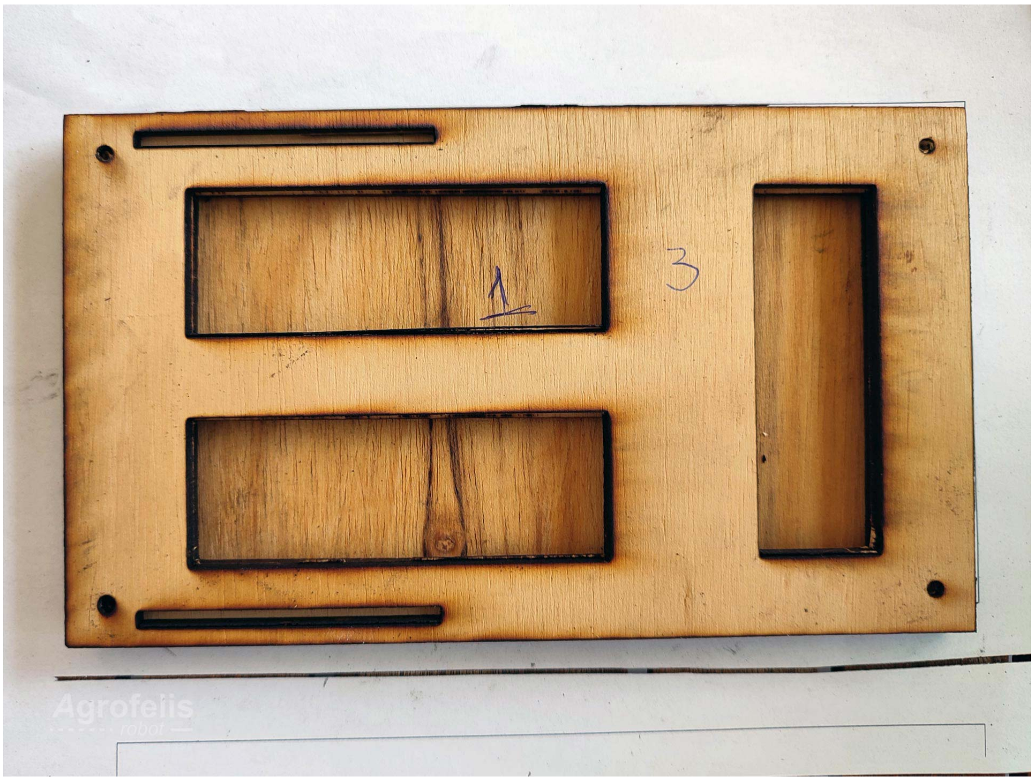


Figure 5: Three laser cut layers of 4 mm plywood stacked to form the bottom body of structural element

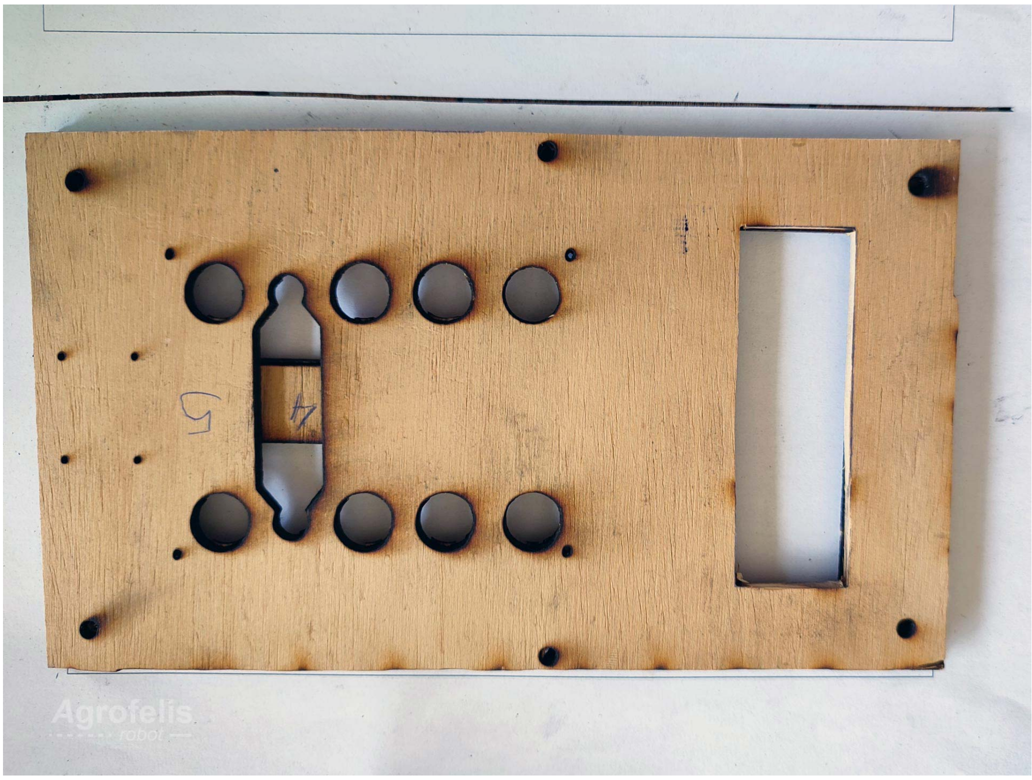


Figure 6: Two laser cut layers of 4 mm plywood stacked to form the top body of they structural element.

The 3d printed air fins glued on the bottom part of the structure are illustrated below.

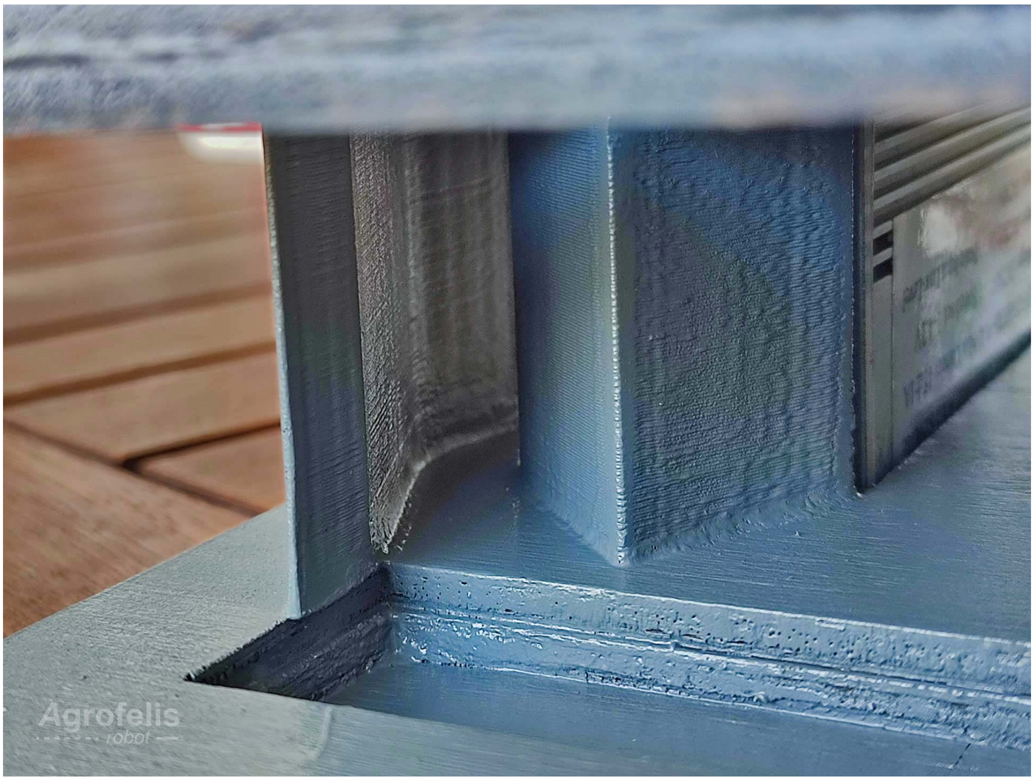


Figure 7: An inner view of the compartment formed via the 3d printed air fins

The bottom and top part and how these fit together using the motor drivers as building blocks, are captured by the following photo.

Figure 8: A front view focusing on the 3d printed air fins guiding the airflow on both sides of the motor drivers

The Motors Hub structure sub-module, is implemented using the following parts:

1. Five 4mm ply-wood layers were cut into 204.83 mm X 119.67 mm parts using a laser cutter. The layers 1-3 form the bottom part and the remaining the top part.
2. Four 3d printed elements guiding the air flow across the sides of the analog motor drivers as well providing extra support to the top layer.
3. Wood glue
4. A spray paint
5. Capton tape to secure the temperature sensors in the top wood layer slot.
6. Eight Standoff, 2mm bolts and screws to mount the Controller and ADAC sub-modules, into the wooden top layer.
7. Two 2.8mm X 16mm screws, securing the top layer with the outer fins.

The schematics and source files to cut and 3d print *parts 1* and *2* are located within the following folders respectively.

- structural/box_wood_layers/laser_cut
- structural/box_fins/3d_print

More specifically, the *laser cut* folder documents the procedure for exporting and transforming the Rhino diagrams into five SVG (scalable vector graphics) files and consequently to five NC (Numerical Control) instructions, used to cut the related parts. The *3d print* folder contains two STL (stereolithography) files (a, b) and two Gcode (geometry code) instruction files for the inner and outer fins structural elements.

Electronic sub-modules

The electronics sub-modules of the Agrofelis Motors hub driver, sum into four PCB sub-modules namely the:

1. Motors hub controller module.
2. Motors hub power module (A).
3. Motors hub power module (B).
4. Motors hub ADAC module.

Their compilation is illustrated by the following diagram.

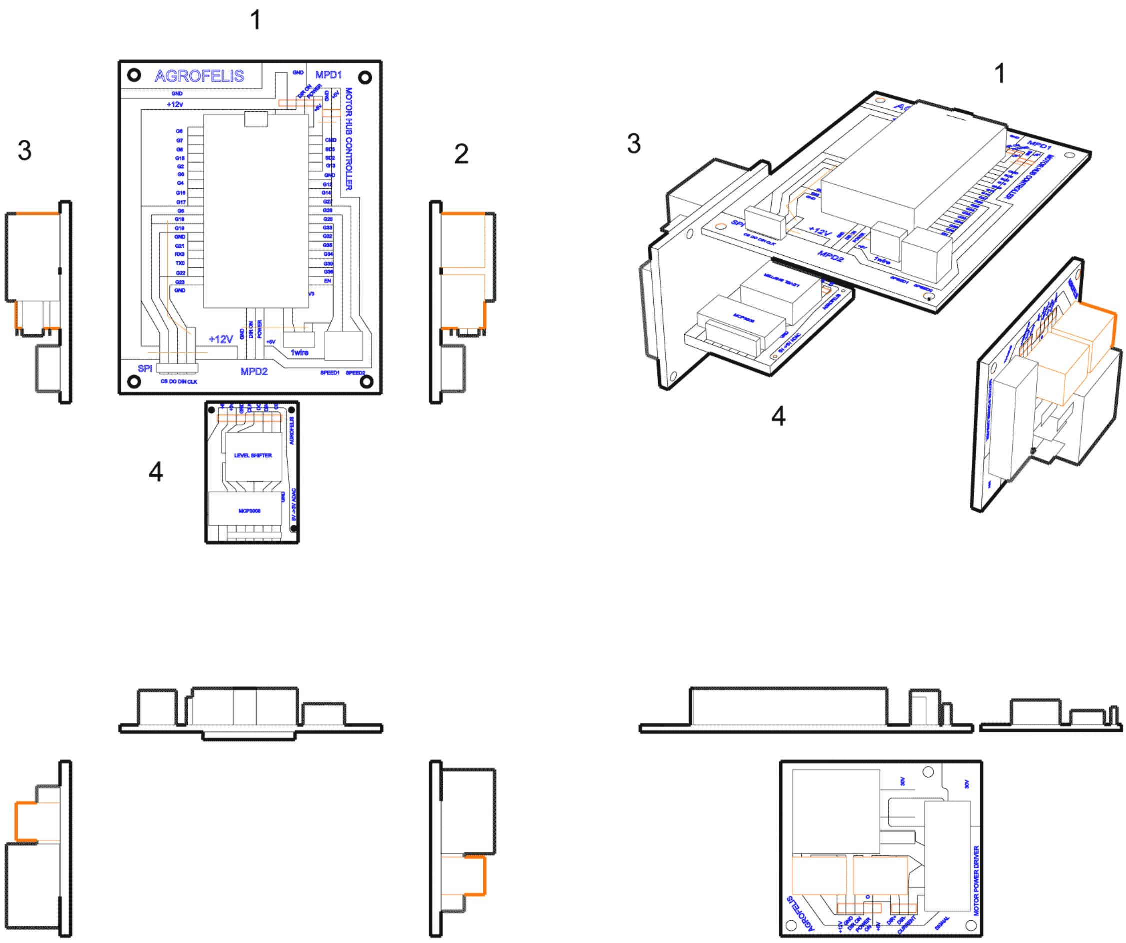


Figure 9: Views of the electronic elements of the microcontroller, attached on the top and left, right sides of the structural component.

In the following sections the three type of modules are documented in further detail.

Motors hub controller

This sub-module of the Motors Hub Driver integrates all electronics components of the overall module. The controller decomposes the functionality of signal processing, sensor impulse broadcasting and for controlling the actuators via wireless means. The module digitally drives the two motor hubs via an ESP32 and reads and intercepts the hall sensors of the analog drivers using the ADAC module. The module senses the current drawn by the motors, reads the individual temperature of the analog drivers and controls the power, the speed and spin direction of the motors.

The PCB is illustrated by the following figure.

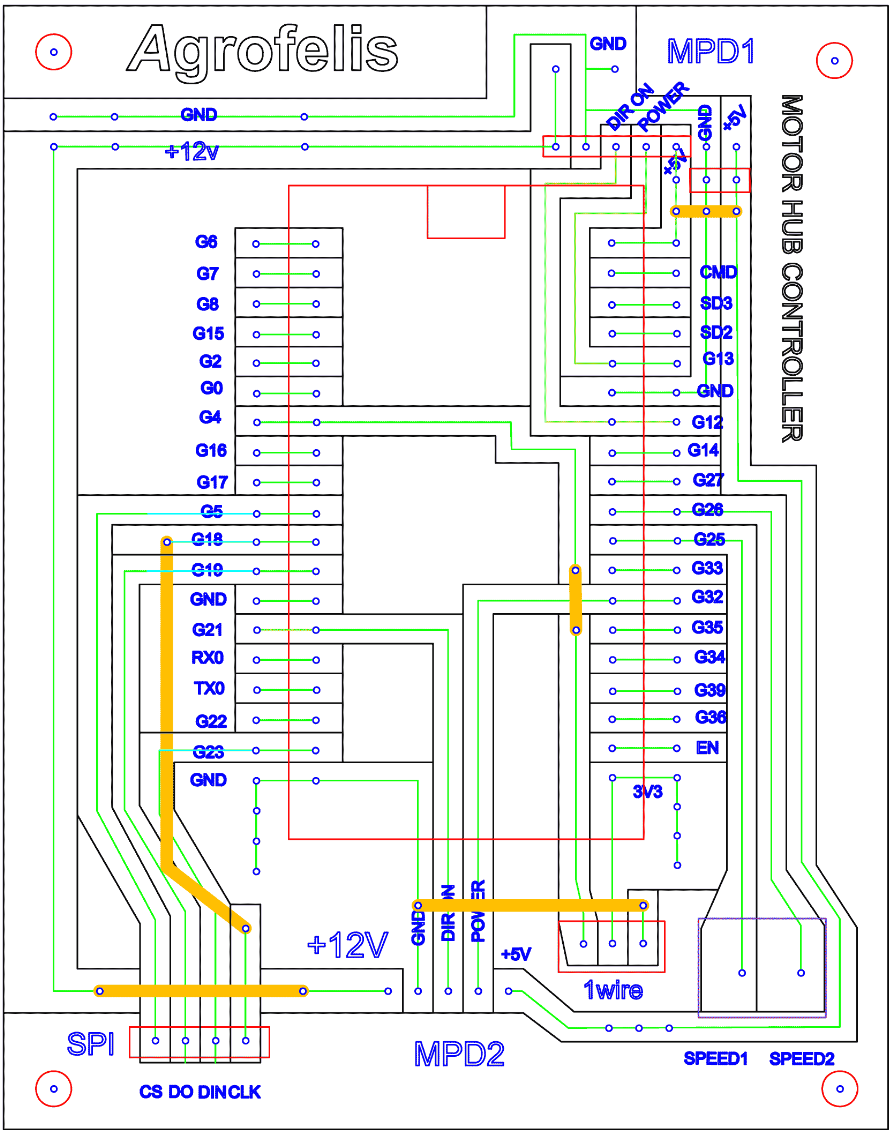


Figure 10: The motors hub driver PCB schematic

Lines in green, indicate a connection between two points in the board. Lines in black offsetting the green lines indicate curves cutting the copper surface, creating the end routes between the connect coordinates in the board. Lines in yellow indicate bridges, connecting two points from the top side of the board via a wire. Lines in red, indicate components or connectors of the board and their orientation.

The Motors Hub controller is composed of the following elements:

1. A PCB board.
2. The printed schematic glued on top of the PCB, indicating the location of components and the underlying routes of the PCB.
3. One ESP32 with 38 pins.
4. Two 20-pin female headers allowing to remove the ESP32.
5. One 2-pin female header for connecting the 12v fan.
6. One 4-pin female header.
7. One 2-pin JST male connector for the 5v supply.

8. One 3-pin JST male and female connector used to connect two temperature sensors via the one wire protocol.
9. Two Green 5mm Screw terminal PCB Connectors, one for the speed link of both motors and one for the 12v input.
10. Two 5-wire 7cm ribbon cable, used to connect the power modules.
11. Two 5-pin female headers used to connect the power modules at the end of ribbon cable.
12. One 3-wire 7cm ribbon cable, used to connect the temperature sensors.
13. Two temperature sensors DS18B20 connected via one wire.
14. Pieces of wire for implementing the PCB bridges as indicated by the yellow color in the PCB.PRINT.Stickers schematic.
15. A case cooler 8cm LogiLink FAN101 at 12V.
16. The Agrofelis Motor Hub Power Driver modules and the Agrofelis Motors hub ADAC module.
17. Non-mandatory connectors, two 2-pin terminal, high current red and black wire, male and female connectors to power the analog motor drivers with.
18. Glue stick to secure the copper side of the pcb from extrernal factors applied after its function has been verified.
19. The software for the back and front dual motor driver.

Remarks:

- One pin is trimmed off the twenty pin female headers, to match each side of the 19 pins of the ESP32.
- The temperature sensor male headers, are removed and connected with the 3-wire ribbon cable, to lower their height profile.

Various listed elements of the controller, are layed out by the following photo.

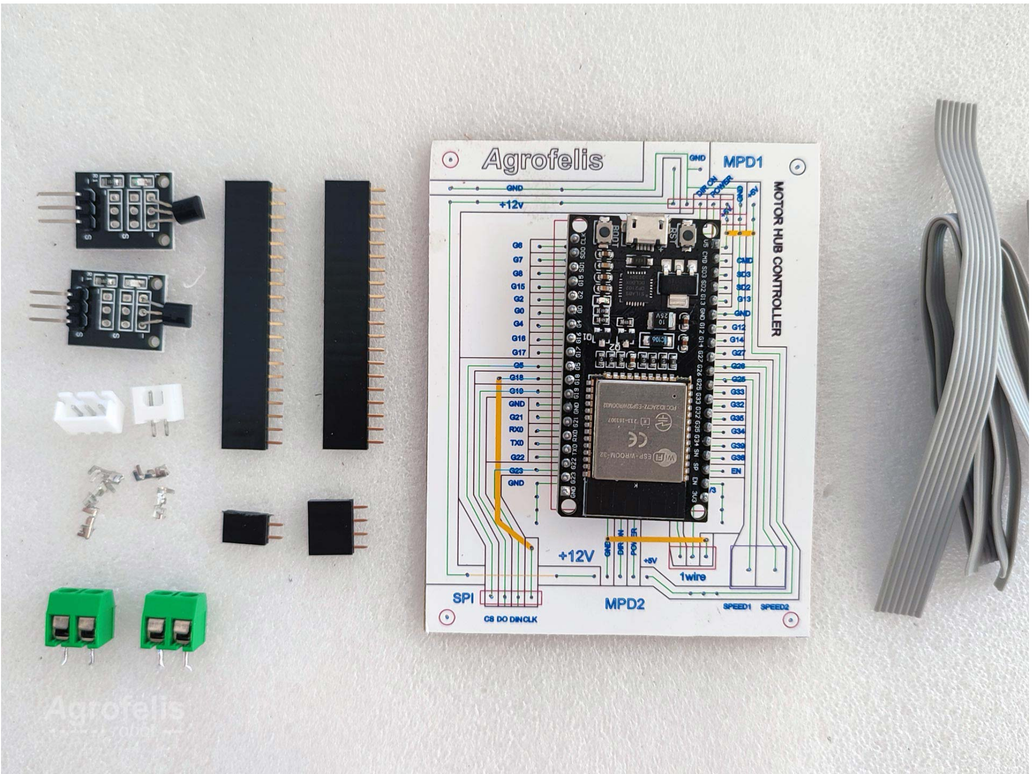


Figure 11: Components composing the Motors hub controller

Below, the module with most of its elements established, is illustrated.

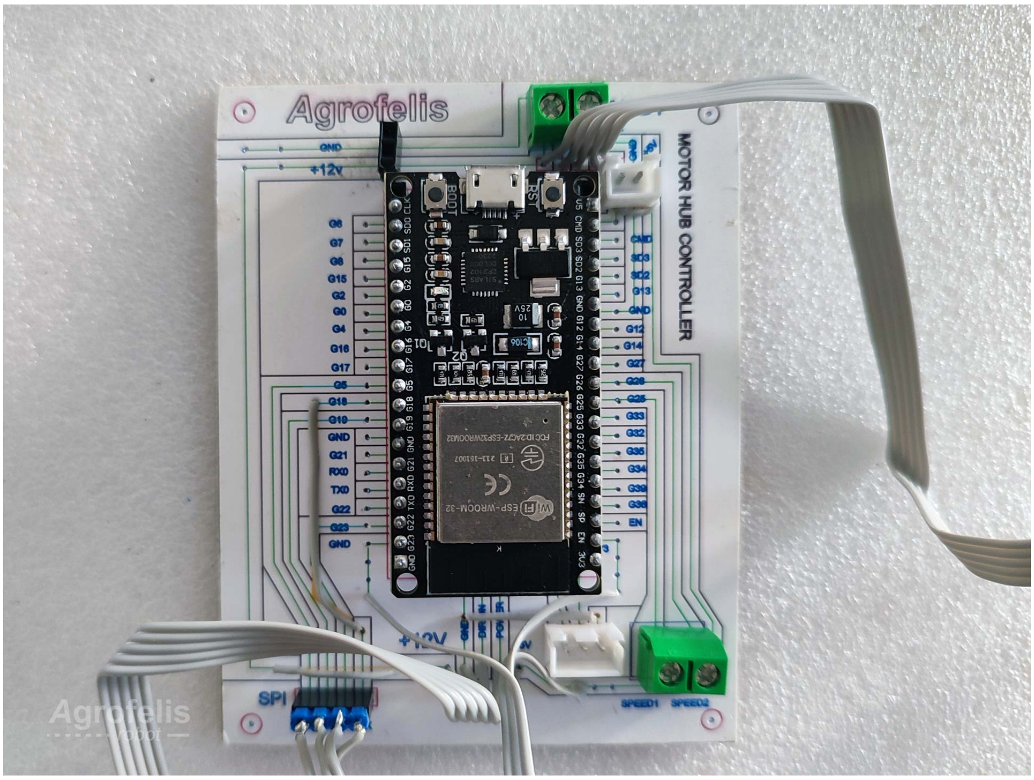


Figure 12: Photo of the assembled motors hub controller

The temperature sensors as positioned and secured using capton tape in the top part of the structural component, are presented below.

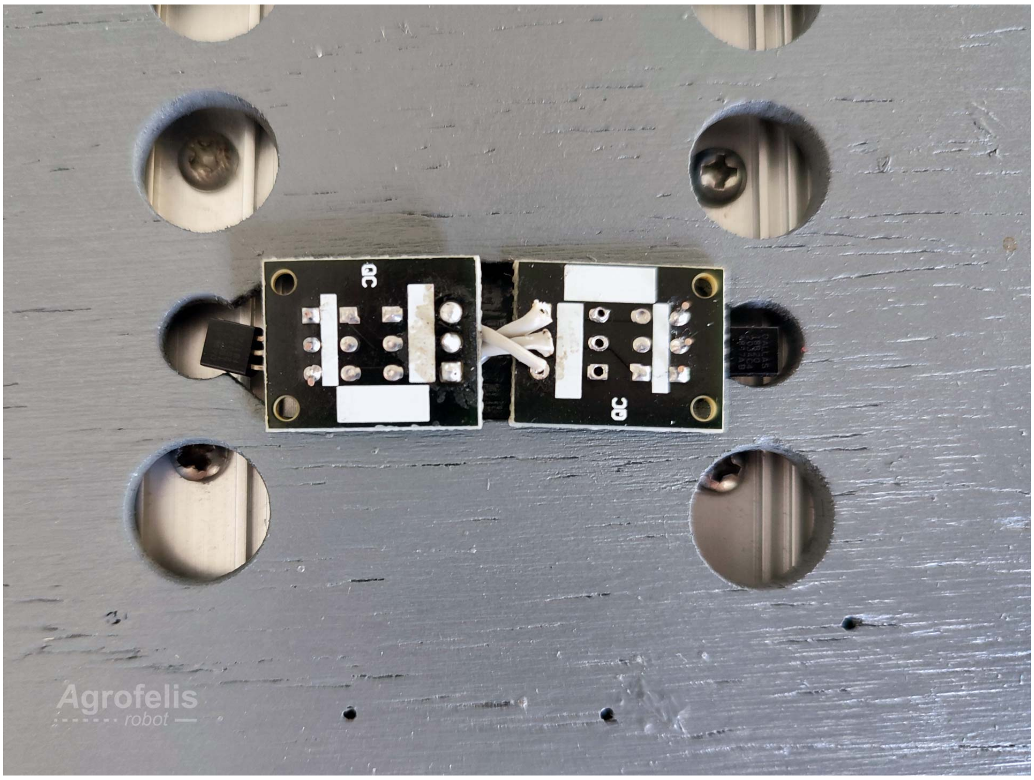


Figure 13: Closeup of the two temperature sensors located in the laser cut slots of the top body of the structural component.

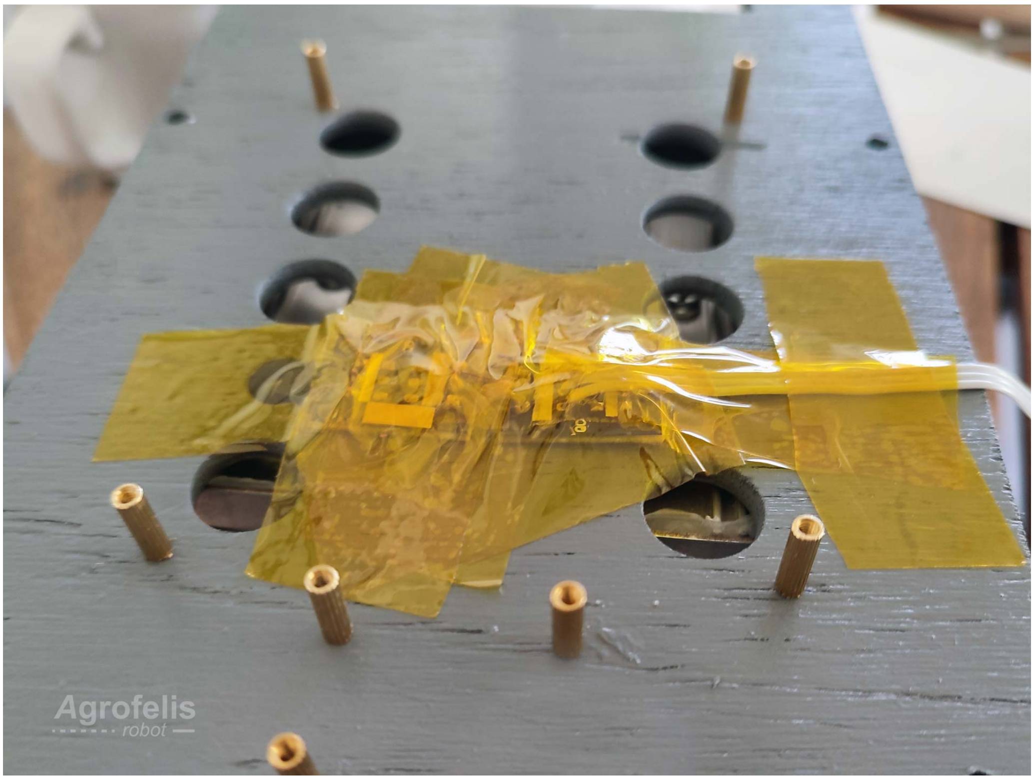


Figure 14: Photo the temperature sensors isolated using temperature resistant capton tape

After the functionality of the board has been verified, the copper side of the PCB is shielded using hot glue to prevent corrosion and improve its longevity.

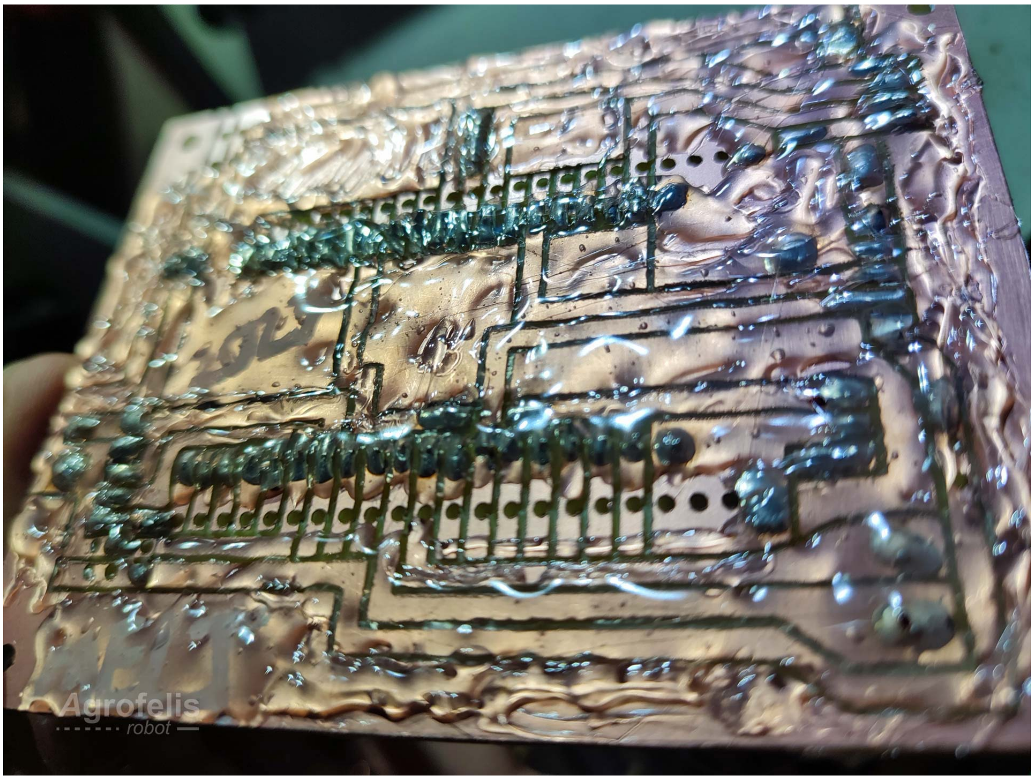


Figure 15: The copper side of the PCB, shielded using hot glue

The schematics and source files to manufacture *part 1* using a regular CNC equipped with a drill, are located within the following folder:

- pcb/PCB.CNC.controller

More specifically, the folder documents the procedure for exporting and transforming the Rhino diagrams into two SVG files and consequently to two NC instructions files, enhanced using two custom JavaScript applications.

- PCB.CNC.controller/readme.md

The PCB board is developed in two phases. The first phase handles the drilling aspect using a drill bit, specifically for this purpose. In the second phase, the drill bit is changed into one appropriate for curving the copper of the PCB.

Within the aforementioned folder, the following respective files encode the desired movements to be perform.

- 1.DRILL.svg
- 2.CURVE.svg

The SVGs are converted into CNC instructions using the open source laserGRBL software. Consequently, using the following JavaScript applications the NC files are enhanced to incorporate Z axis movements based on the continuity and the coordinates of the schematics and the scope of the instructions (drilling or routing).

- LineRoutesToHoles.html
- LineRoutesToWire.html

The end instructions to reproduce the board are the:

- 1.DRILL.ENHANCED.nc
- 2.CURVE.ENHANCED.nc

The first pattern indicating the paths visiting each hole to make and the second pattern indicating the curves to route, are illustrated by the following figure.

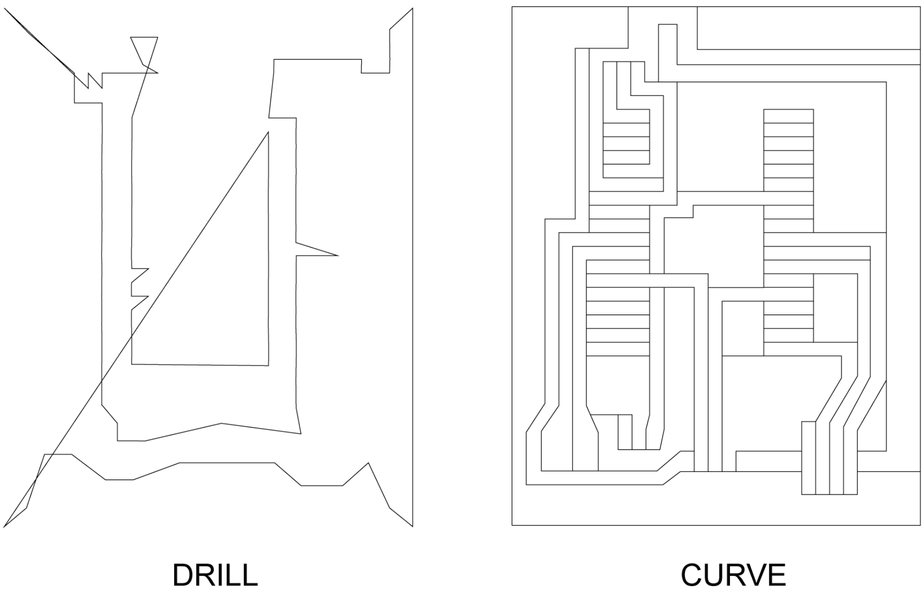


Figure 16: The PCB's drilling and curving patterns

The top non conductive cover of the PCB is enriched with a diagram printed in photographic paper, glued and punctured using a needle. The related PDF containing more than one diagram to cover four pcb, is stored in the following folder.

- PCB.PRINT.Stickers/motors_hub_driver-sticker-pcb-controller.pdf

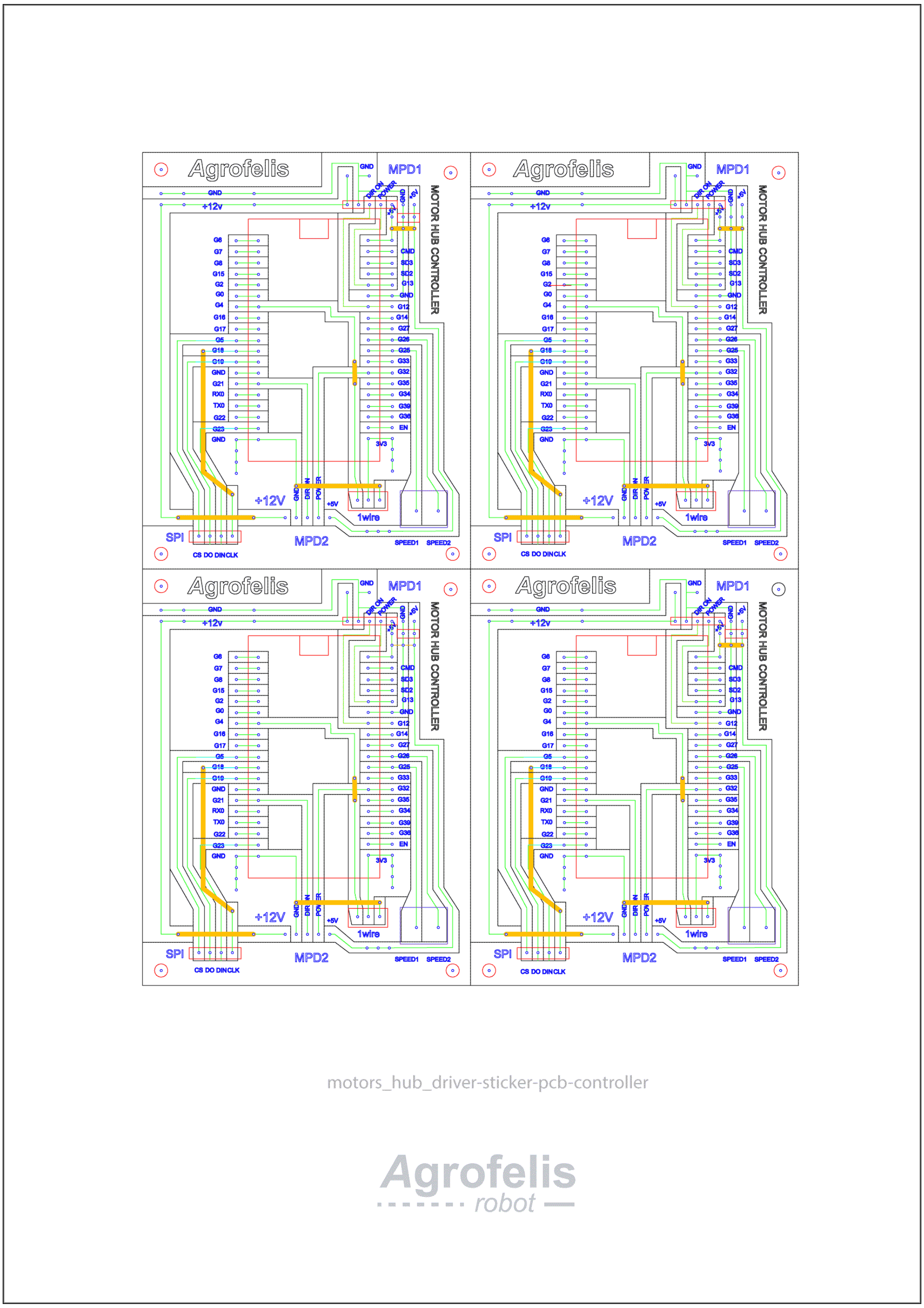


Figure 17: Multiple layout covers of the PCB, printed on an A4 page, cut and glued on the top side of controller

Motor hub power module

This sub-module of the Motors Hub Driver decomposes the functionality of powering , sensing the current and reversing the direction of a motor hub driver.

Two identical modules are employed for the first and second motor driver mounted on the left and right side of the structural component of the module, vertically within the curved slots. The power modules interfaces with the Motors hub controller using a 5-wire ribbon cable carrying 12v & 5v, and the signals for activating two relays, one controlling the direction of the motor and another chained with a large relay supplying high current power to the motor driver. The module interfaces indirectly with the controller module via the ADAC module capable of monitoring a 5v signal and more specifically with the current sensor of the power module.

The PCB is illustrated by the following figure.

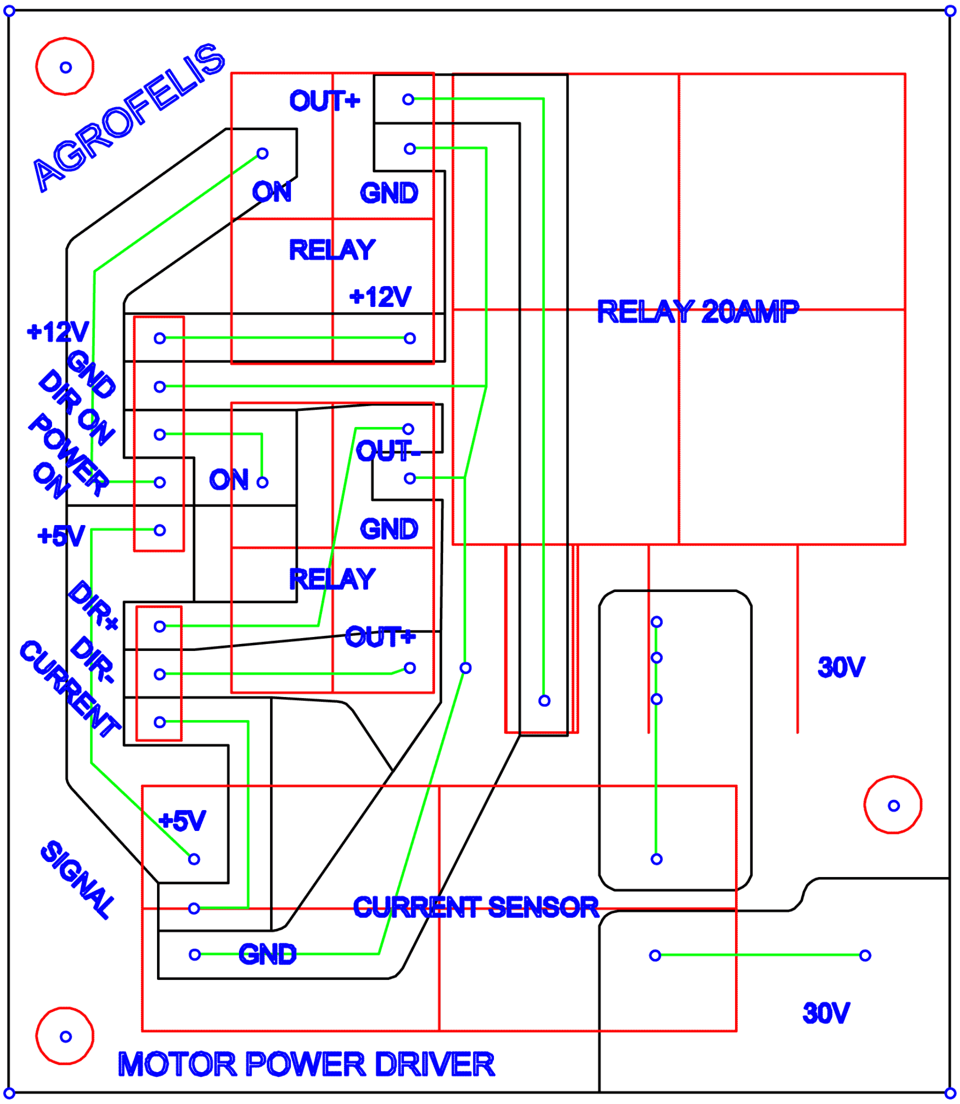


Figure 18: The PCB layout diagram of the Motor hub power module component

Lines in green, indicate a connection between two points in the board. Lines in black offsetting the green lines indicate curves cutting the copper, creating the end routes between connected points in the board. Lines in yellow, indicate bridges connecting two points from the top side of the board via a wire. Lines in red, indicate components or connectors of the board and their orientation.

The PCB is manufactured using a low budget VEVOR CNC 3018 Pro.

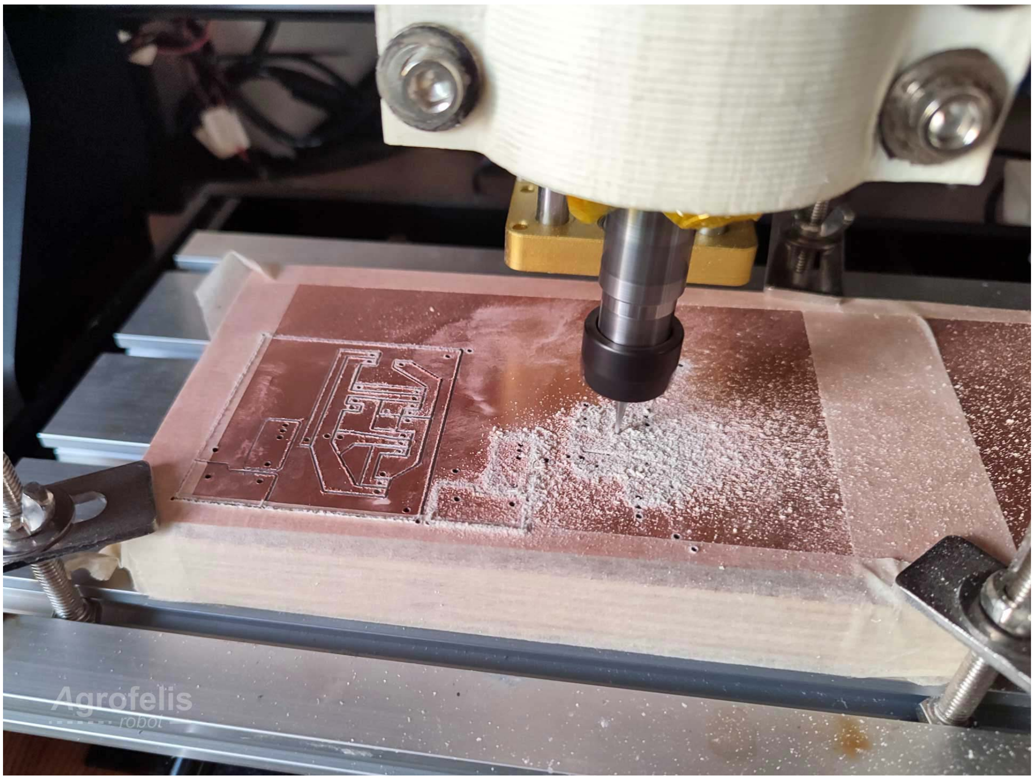


Figure 19: A low cost CNC mounted with a drill, curving an one side copper plated PCB fabricating the Motor hub power module

The Motors Hub Power Driver is composed of the following elements:

1. A PCB board, with its schematics located within PCB.CNC.power/ folder.
2. The PCB top side printed cover located within PCB.PRINT.Stickers.
3. Two relays trigger/able with 3v [HK4100F-DC 3V SHG Relay 6Pin].
4. One car relay, trigger/able with 12v with 20 amp capacity [6770718 - 12v 20A].
5. An [ACS712] 20 amp current Sensor.
6. One 5-pin male header.
7. A JST-SM 2-pin connector, connecting with the motor driver reverse function.
8. One small wire for connecting the PCB with the 20 amp relay.
9. One 3-pin header for connecting the PCB with the 20 amp relay.
10. One 4cm high current wire.
11. One 6.2mm female connector.
12. Glue stick to secure the copper side of the pcb from corrosion.
13. Two 40v 1amp diodes, protecting the digital GPIO of the ESP32 from the back voltage, potentially generated by the Relay coils.

This sub-module is used twice, within the Motors hub driver module.

Remarks:

- Two pins of the 3v relays are trimmed as illustrated in the schematics, interfacing with the PCB with only the utilised pins.
- The ACS712 20 amp current sensor pins/connectors are de-soldered and pins are soldered from the bottom side of the sensor's PCB, interfacing with the PCB of the module.
- It was noticed that not all HK4100F-DC 3V were operational with ESP32. About 45% of these relays are manufactured more efficiently and are triggerable by the low amp digital output of the ESP32. During tests those found to cooperate with the ESP32, were triggerable with less voltage, 1.8v, while the non triggerable ones required at least 2v. This issue can be

mitigated by employing a ULN2003 relay driver circuit IC, which could be integrated in either the power module or the controller module.

- A diode not depicted by the photos is installed in parallel with the relay's triggering pins.

Various elements of the controller are layout by the following photo.

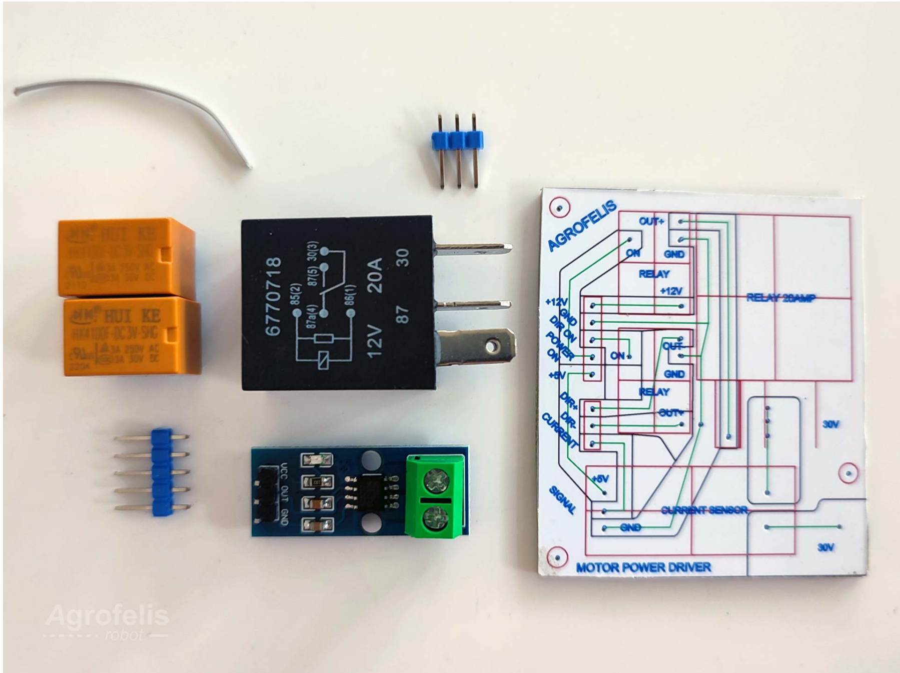


Figure 20: A photo of the parts composing the Motors hub driver module

Below, the module and details for establishing its components, are provided.

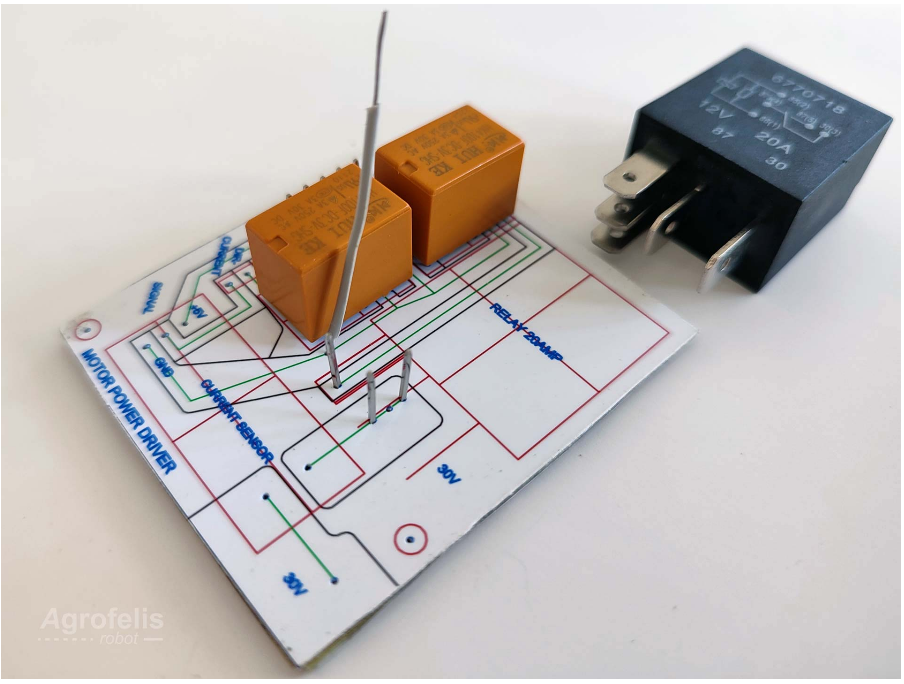
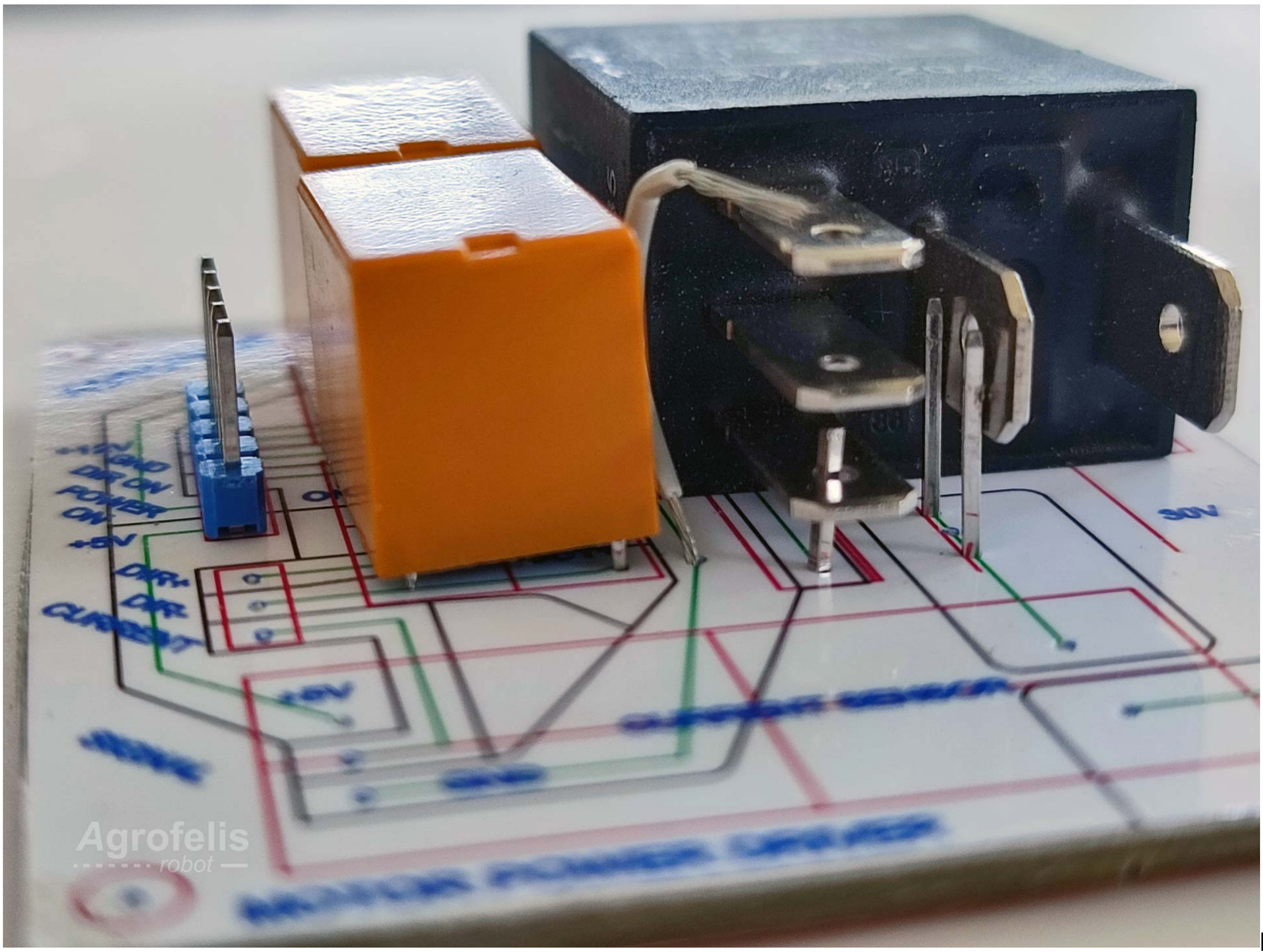


Figure 21: Close up of the pins and wire used to mount the 20 amp Relay on the PCB



[70]

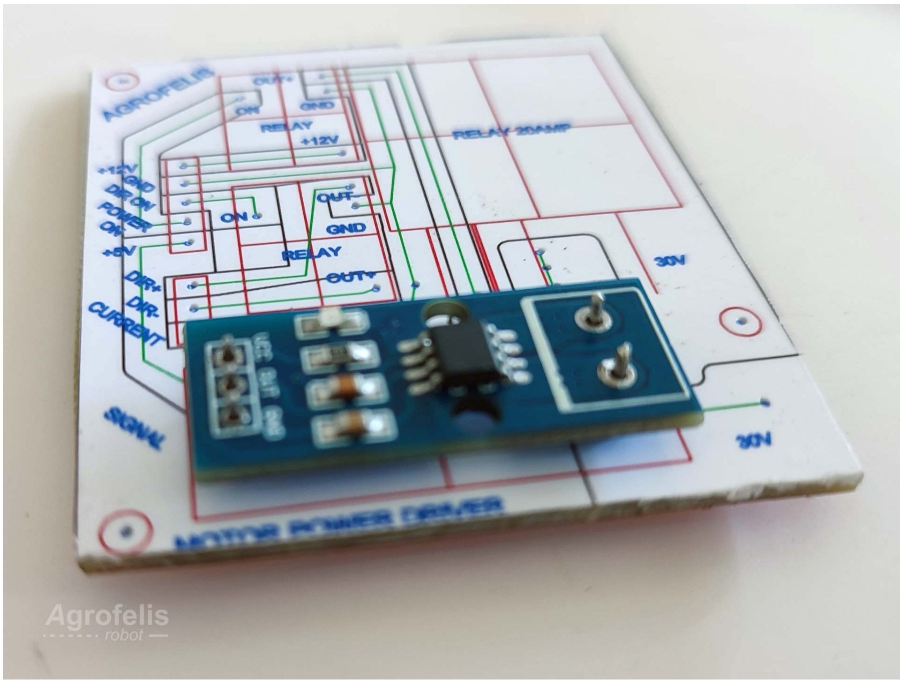


Figure 22: Close up photo of the current sensor, mounted on the PCB

The bottom/copper side of the assembled module, is captured below.

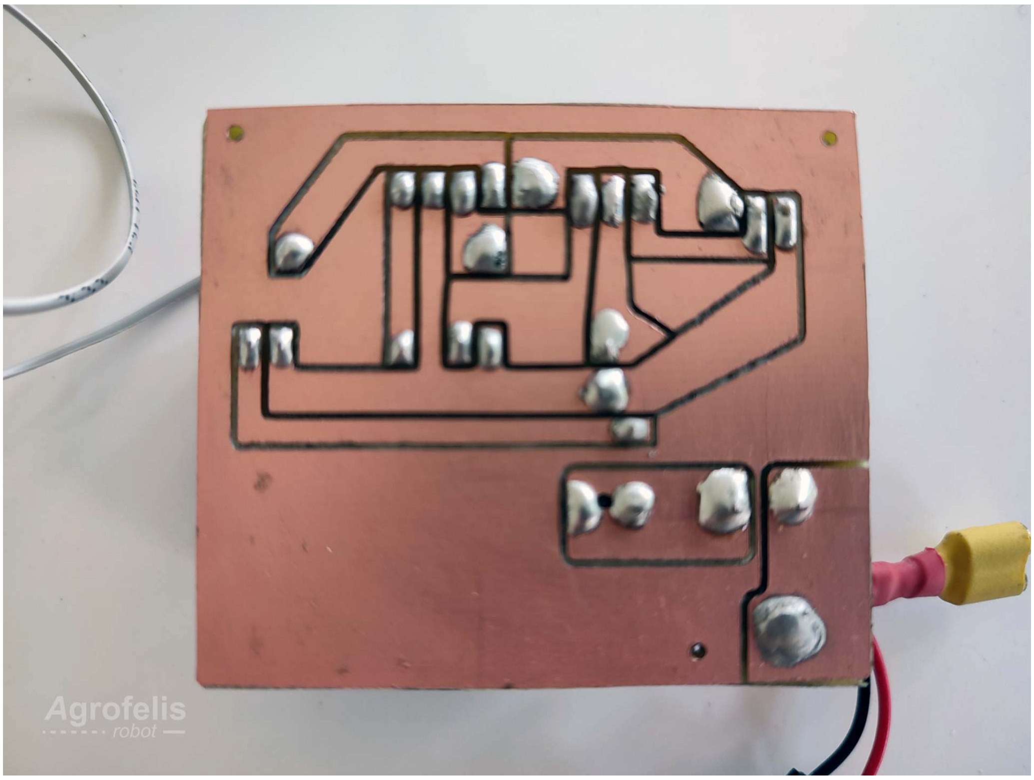


Figure 23: The copper side of the implemented PCB

The assembled module with its counterpart, are captured by the following photos.

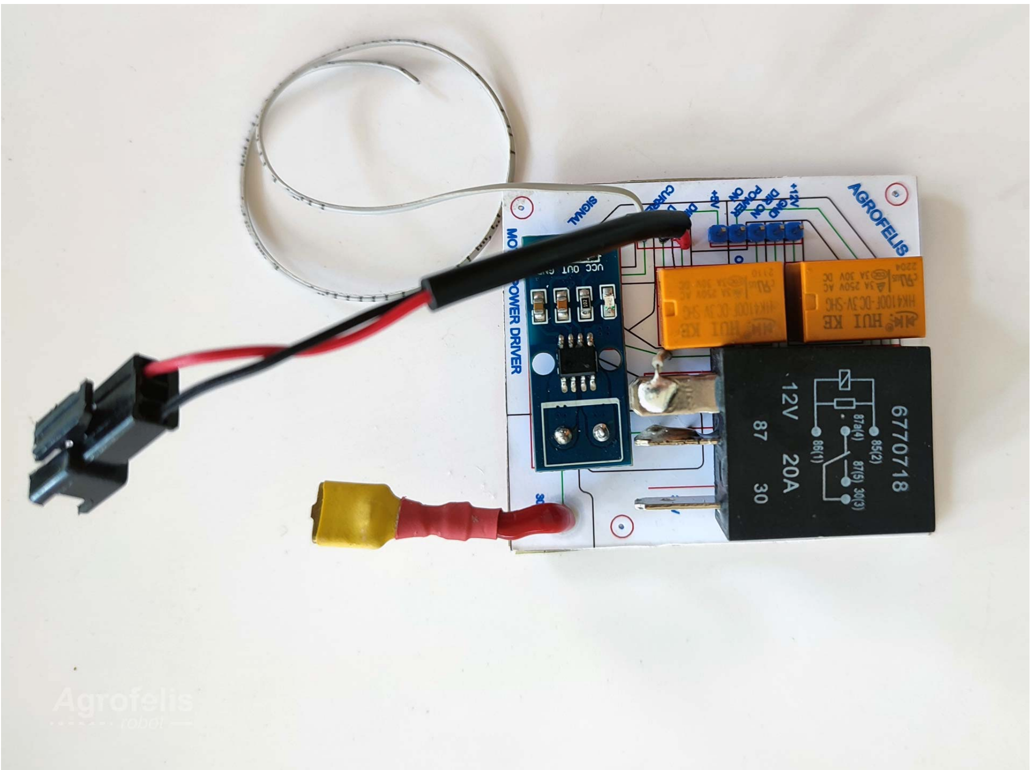


Figure 24: The implemented motor hub power module

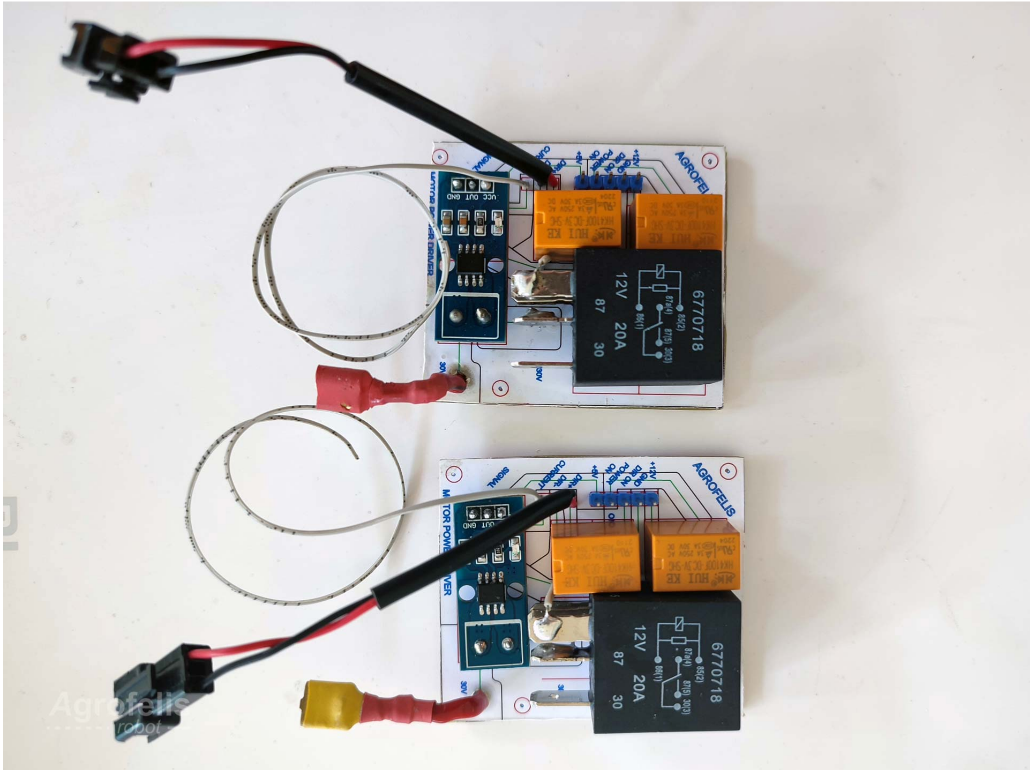


Figure 25: The two motor hub power modules ready to be mounted into the sides of the structural component

After the functionality of the board was verified, the copper side of the PCB was shielded using hot glue to prevent corrosion and improve its longevity.

The schematics and source files to manufacture *part 1* using a regular CNC equipped with a drill, are located within the following folder:

- pcb/PCB.CNC.power

More specifically. the folder documents the procedures for exporting and transforming the Rhino diagrams into two SVG files and consequently to two NC instructions files, enhanced using two custom JavaScript applications.

- PCB.CNC.power/readme.md

The PCB board is developed in two phases. The first phase handles the drilling, using a drill bit appropriate for drilling. In the second phase, the drill bit is changed into an appropriate one for curving the copper of the PCB.

Within the folder, the following respective files encode the related movements to be followed by the CNC.

- 1.drill.svg
- 2.curve.svg

The SVGs are converted into CNC instructions using the open source laserGRBL software. Consequently, using the following JavaScript applications developed, the NC files are enhanced to incorporate Z axis movements based on the continuity and co-ordinates of the schematics and the scope of the instructions (drilling or routing).

- LineRoutesToHoles.html
- LineRoutesToWire.html

The end instructions to reproduce the board, are the:

- 1.drill.normalised.enhanced.nc
- 2.curve.normalised.enhanced.nc

The first pattern indicating the paths visiting each hole to make and the second pattern indicating the curves to route, are illustrated by the following figure.

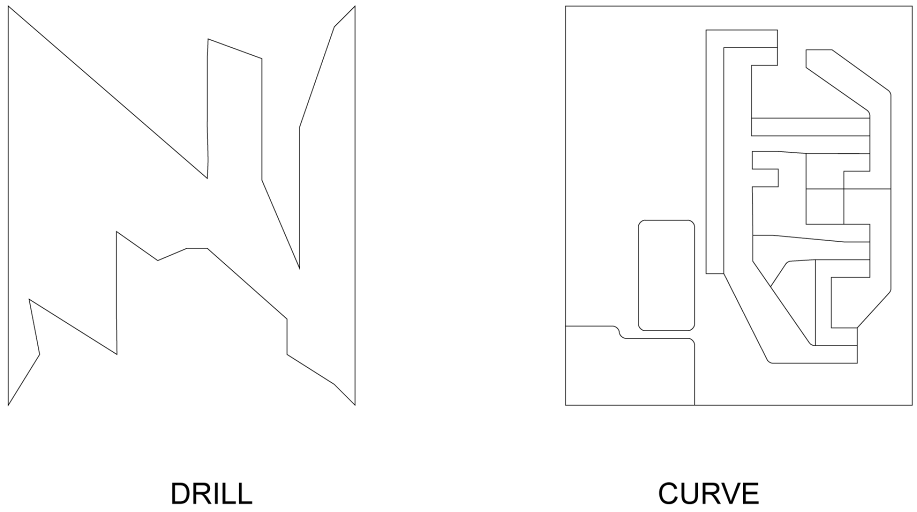


Figure 26: The PCB's drilling and curving patterns

The top non conductive cover of the PCB is enriched with a diagram printed in photographic paper, glued and punctured using a needle. The related PDF containing more than one diagram to cover nine PCBs, is stored in the following folder:

- PCB.PRINT.Stickers/motors_hub_driver-sticker-pcb-power_driver.pdf

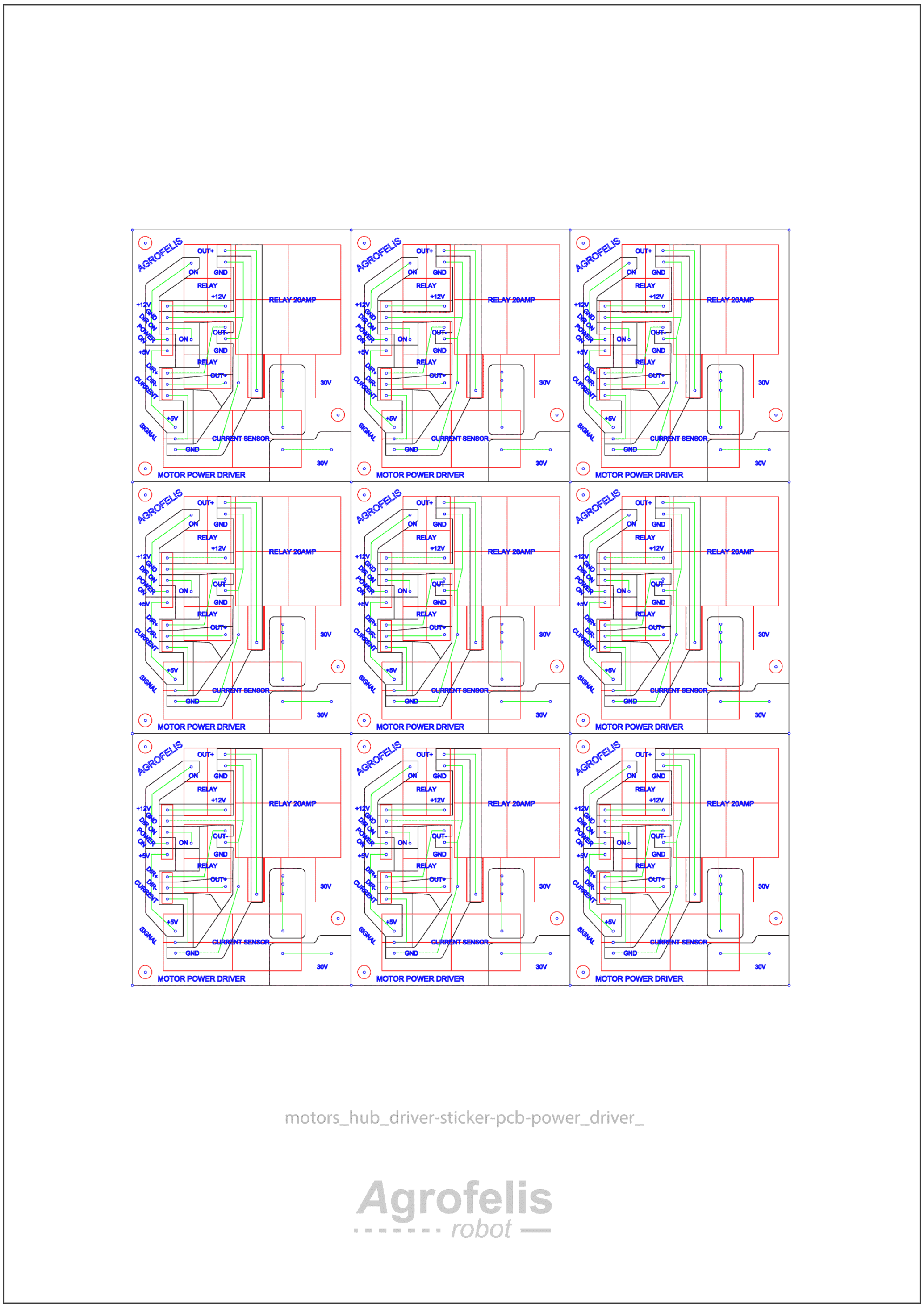


Figure 27: Multiple layout covers of the PCB, printed on an A4 page, cut and glued on the top side of controller

Motors hub ADAC

This sub-module of the Motors Hub Driver allows to interface 5v sensors with ESP32, operating at 3.3v via a bidirectional logic level conditioner. Moreover, using an external ADAC the module can handle additionally 4 analog channels, enough so an ESP32 can operate and sense two motor drivers simultaneously.

The module interfaces with the two current sensors signals of the power modules as well as with the six hall sensors, tracking the rotation of the motors hubs.

The PCB is illustrated by the following figure.

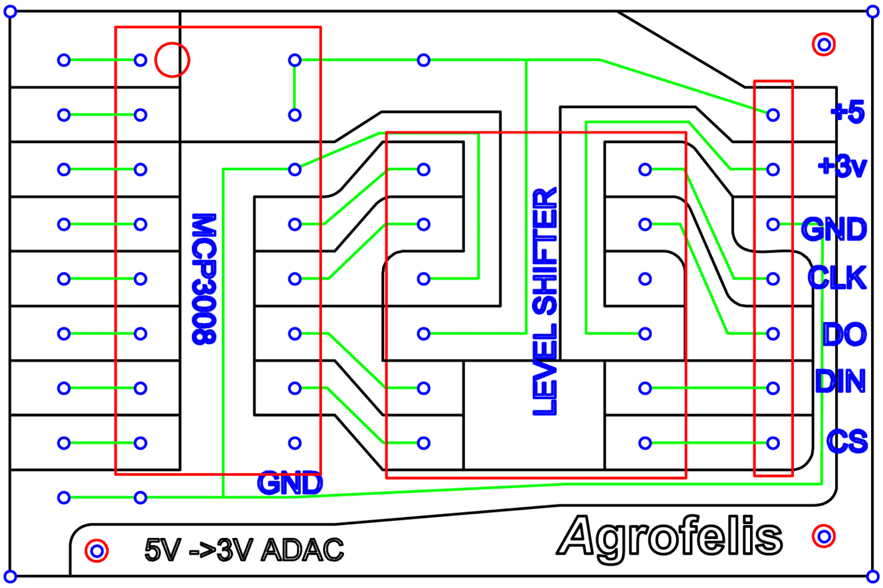


Figure 28: Motors hub ADAC PCB layout

Lines in green, indicate a connection between two points in the board. Lines in black offsetting the green lines, indicate curves cutting the cooper, creating the end routes between connected points of the board. Lines in yellow, indicate bridges connecting two points from the top side of the board via a wire. Lines in red, indicate components or connectors of the board and their orientation.

The Motors Hub ADAC is composed of the following components:

1. A PCB board, with its schematics located within PCB.CNC.adac/ folder.
2. The PCB top side printed cover located within PCB.PRINT.Stickers.
3. One MCP3008 8-channel 10 bit ADC.
4. One 4-channel I2C safe Bi-directional Logic Level Converter between 5V and 3.3V.
5. One 7-pin ribbon cable for connecting with the ADAC module.
6. One 4-pin male header for connecting with the Agrofelis controller.
7. One 8-pin female header.
8. Two 7cm single wire cables connecting the ADAC with the current sensors of the Agrogelis Motor Power driver.
9. Glue stick to secure the copper side of the PCB from extrernal factors applied after its functionality has been verified.

Remarks:

- The first and second channels of the MPC3004 ADAC are connected to the current sensors of the power module.
- The remaining channels of the ADAC are connected with the hall sensors of the motor. The Hall sensors signals connected between the motor and the analog motor drivers are intercepted following the yellow, green, blue, yellow, green, blue and closing with the ground.
- The ground of the halls sensors outlet, is connected with the ground pin of the Motors hub ADAC module.
- One pin from the 8-pin female header, is trimmed off to match the 7 input pins of the module.

Various listed elements of the sub-module, are layout by the following photo.

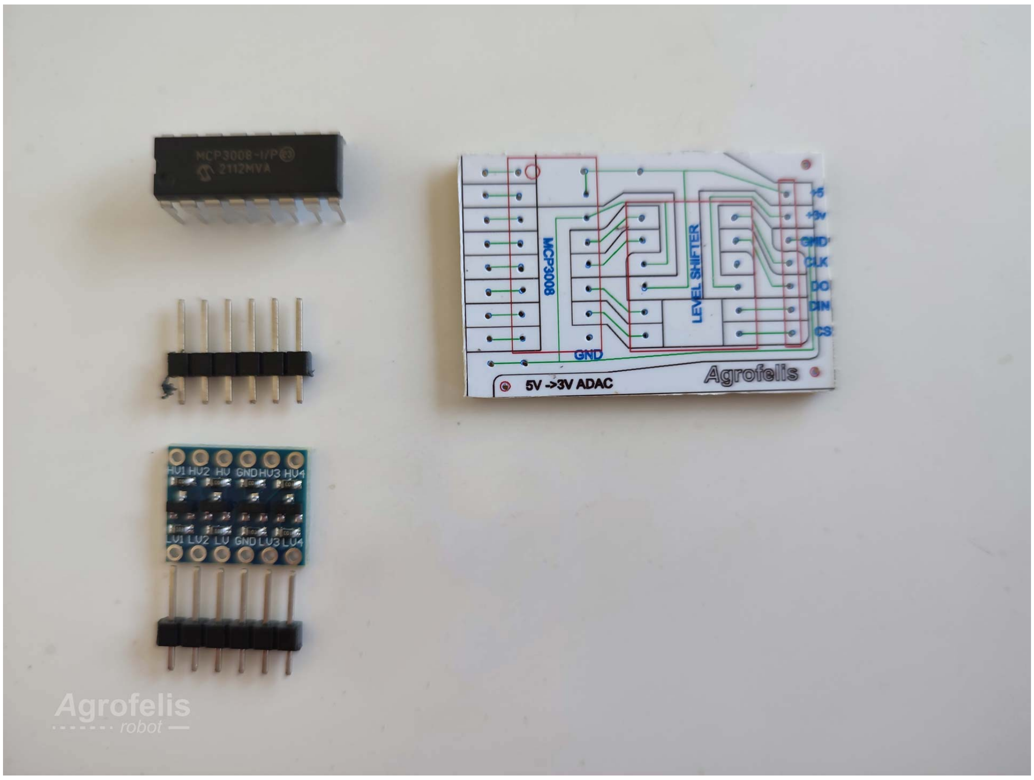


Figure 29: The components composing the Motors hub ADAC module

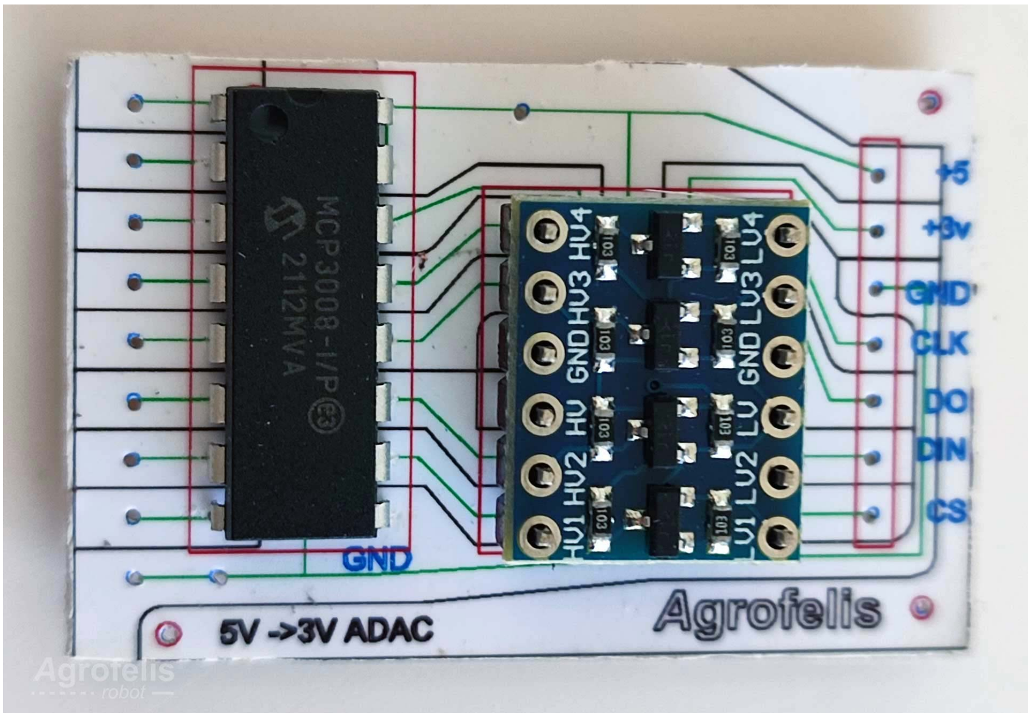


Figure 30: The module with its components mounted in the PCB

The module interfaces with the controller module via the SPI interface, as depicted by the following photo.

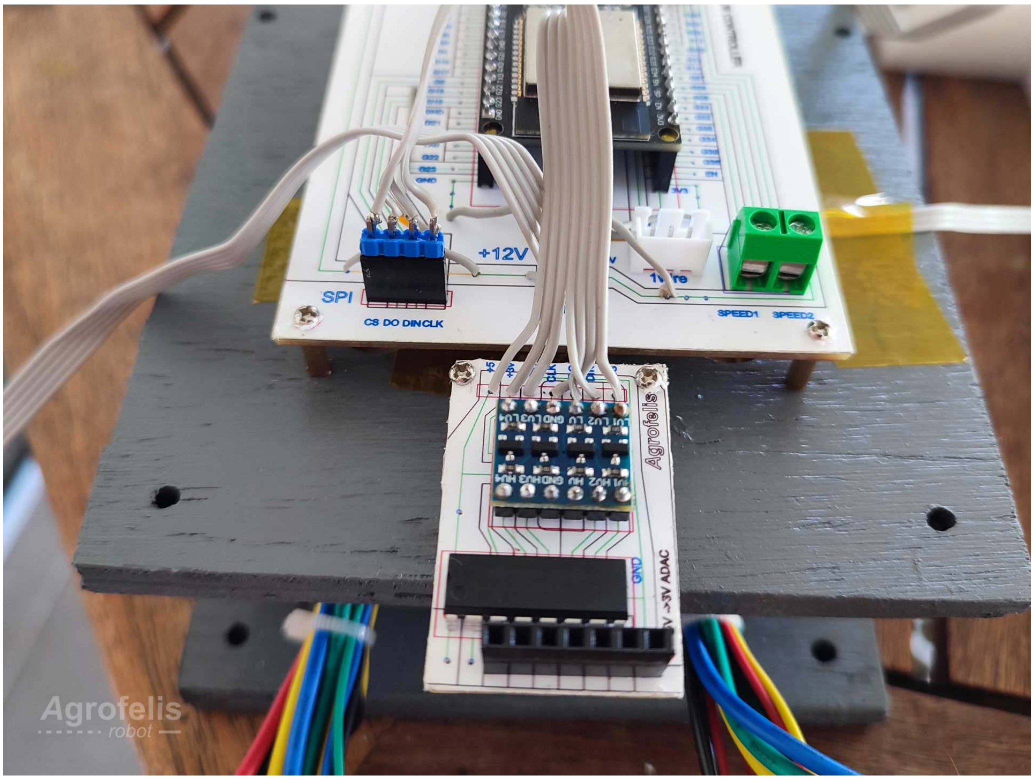


Figure 31: The Motors hub ADAC module connected with controller and mounted on the top part of the structural component

After the functionality of the board was verified, the copper side of the PCB was shielded using hot glue to prevent corrosion and improve its hardness.

The schematics and source files to manufacture *part 1* using a regular CNC equipped with a drill, are located within the following folder:

- pcb/PCB.CNC.adac

More specifically the folder, documents the procedure for exporting and transforming the Rhino diagrams into two SVG files and consequently to two NC instructions files, enhanced using two custom JavaScript applications.

- PCB.CNC.adac/readme.md

The PCB board is developed in two phases. The first phase handles the drilling, using a drill bit appropriate for drilling. In the second phase, the drill bit is changed into one appropriate for curving the copper of the PCB.

Within the folder, the following respective files encode the desired movements to be action-ed.

- 1_DRILL.svg
- 2_CURVE.svg

The SVGs are converted into CNC instructions using the open source laserGRBL software. Consequently, using the following JavaScript applications the NC files are enhanced to incorporate Z axis movements based on the continuity, the coordinates of the schematics and the scope of the instructions, as drilling or routing.

- LineRoutesToHoles.html
- LineRoutesToWire.html

The end instructions to reproduce the board, are the:

- 1_DRILL.normalised.enhanced.nc
- 2_CURVE.normalised.enhanced.nc

The first pattern indicating the paths each drill follows and the second pattern indicating the curves to route, are illustrated by the following figure.

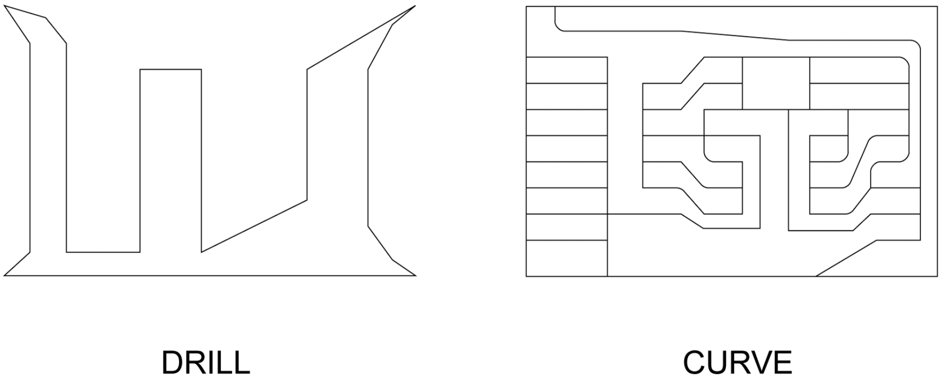


Figure 32: The PCB's drilling and curving patterns

The top non conductive cover of the PCB is enriched with a diagram printed in photographic paper, glued and punctured using a needle. The related PDF containing more than one diagram to cover, eight PCBs, is stored in the following folder:

- PCB.PRINT.Stickers/motors_hub_driver-sticker-pcb-adac.pdf

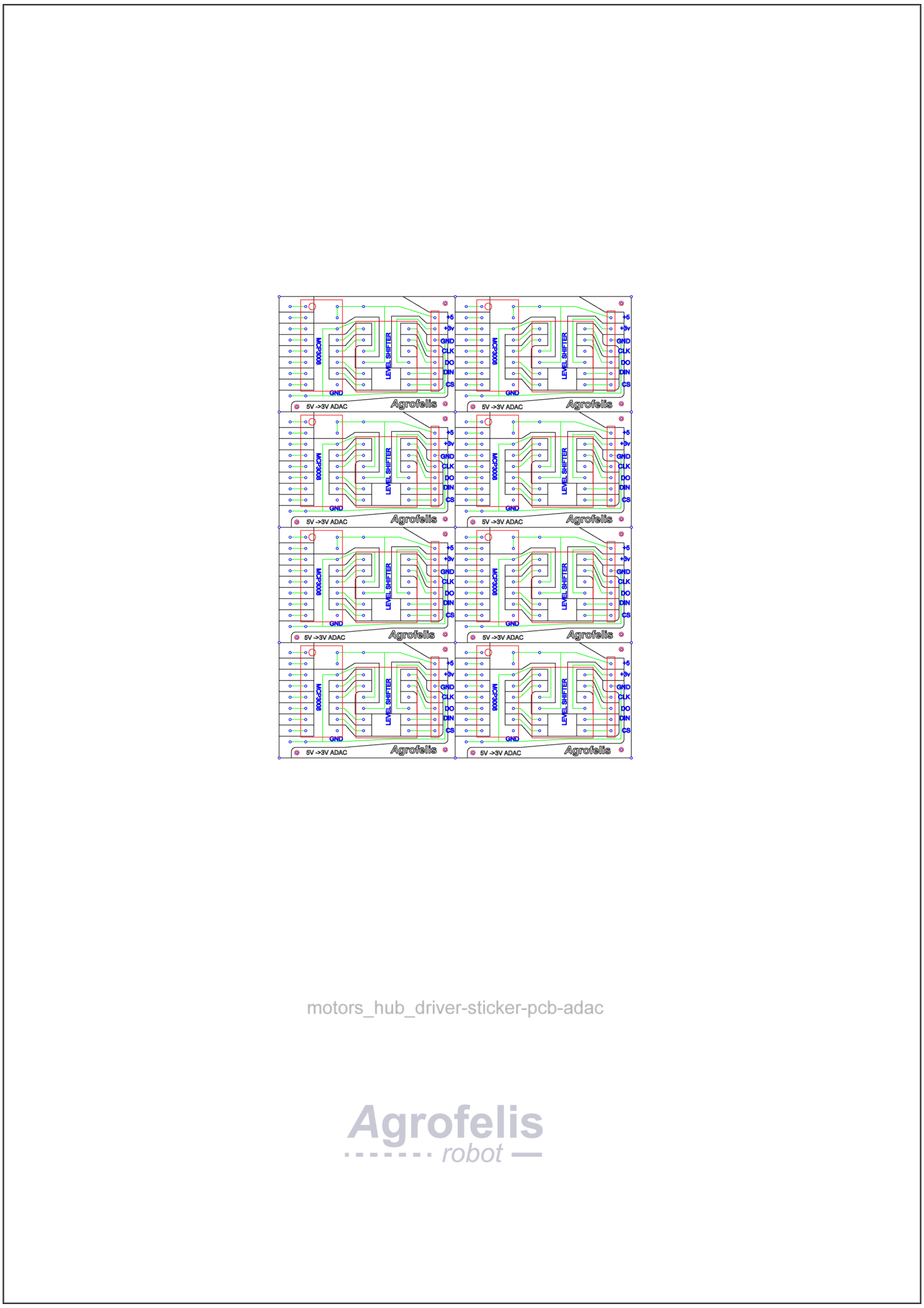


Figure 33: Multiple layout covers of the PCB, printed on an A4 page, cut and glued on the top side of controller

Agrofelis Motors Hubs Software

The software of the modules is contained within the src folder. The software is composed of a C++ application and web application developed to reflect and control the internal state of the microcontroller.

The repository contains two instances of the C++ software, corresponding to the front or the back motor hub drivers, controlling a total of four wheels persisted in the following paths. The software primarily differentiates in declaring the identifier of the module.

- DualMotorDriverFront
- DualMotorDriverBack

Driver Structure

This *Agrofelis Motors Hubs Driver Software* adheres to a common baseline pattern that has been established in nearly all Agrofelis modules. This baseline pattern introduces a "context" class, which is passed to practically all classes as a common ground, enabling instances to exchange information when necessary. The second baseline pattern established refers to the frequency of execution, providing the facilities to trigger specific functionalities at desired intervals. This design consideration accommodates components like the gyroscope, or in our case the hall sensors, which require much more frequent updates compared to components such as GPS or potentiometer sensors. As a bootstrap template, the software provides six different execution frequencies, ranging from 50 milliseconds to 5-second intervals. Using this approach, delays blocking the execution are avoided and the different calls can be organized based on their responsiveness requirements.

The software encodes easy to follow concrete implementations such as current sensors and motor(s), resulting in a one-to-one mapping between the physical element and its respective software counterpart.

The core of the project revolves around an ESP32 microcontroller and various components used to sense and control two motor hub drivers, each capable of delivering 250 watts of power. The module leverages web sockets to share the internal state of the components as well as to control it. This approach provides a robust interface with a compact communication protocol, enabling multiple actors to view, control or relay information from the module. The software initializes both a web and a WebSocket server, facilitating over-the-air firmware updates. The module itself comprises an ESP32, a logic-level shifter, two current sensors and six relays, two of which are connected in series with a high-amperage relay (rated at 20 amps).

The software monitors all sensors, detects hardware errors, allows to remotely action commands operating the module and adapts the voltages dynamically to reach and maintain the desired actuation across the two motors.

The following table indexes and summarizes the implemented classes of the Agrofelis motors hub driver software.

Class	Description
DualMotorDriverBack.ino and DualMotorDriverFront.ino	Boots the application, initialises the top classes and encodes the triggering frequencies of various functional elements.
Context	Provides a common ground for sharing information and encodes the triggering frequencies, helpful functions and a unique identifier of the model. The object more over hosts the two DallasTemperature sensors reading facilities by tapping to the Onewire interface. The class also encodes the identifier of the module, annotating the reflected indicator data.
Invoker	Tracks the execution frequencies so these are called at the right time.
CommandParser	Base class for monitoring and parsing the web socket interface. The class defines the function parsing compact commands of the form <1|1>, where the first parameter corresponds to the applicable action number and the second is an integer value used by the related action.
ADAC	Class establishing the unctions for utilizing the MCP3008 8 channel 10 bit analog ADAC paired with a level shifter connected using the SPI interface
Sensor	Base class wrapping the functions conveying a sensor. The class reads an analogue port when the apply function is being triggered. The class maintains a gated smoothing read out of the sensor by comparing the previous mean with the current read value. Moreover, when a movement is detected based on the absolute difference of the first derivative, a boolean flag is maintained. Lastly, it prints out the object's internal state on print(), reflecting the sensor's port, smoothed value, un-smoothed sensor value and whether or not the sensor is detecting a movement.
SensorADACCurrent	Class extending the *Sensor class* reading the date over the ADAC and implementing the specialties of a current sensor. The class translates raw sensor values to amperage. Moreover, because the current sensor reads rapid current spikes that can be missed, the class maintains a decaying max read value that is renewed based on the maximum observed value within a time window.

Class	Description
SensorHalls	The class reads and decodes the 3 hall sensor values in high frequency and derives the rotational change in positive or negative rotation. The class can detect a problem in the ADAC interface, detect if there is power and also detect if the sensors have missed a step. Lastly the class tracks the cumulative wheel rotation, functioning as an odometer as well as an absolute position. The class is utilised by the Motor class.
Motor	The class implements the control and sensing of the motor by utilizing the SensorADACCurrent, the SensorHalls and the temperature sensor. The class tracks the motor's state, current, projected and desired rotational speed and adapts the voltage driving the motor accordingly. The class implements the function to rotate the motor either forward or backwards or to maintain a particular rotational speed via the feedback mechanism accounting for external factors, such as resistance. The class tracks the temperature and current and cuts off the power to the module if excessive heat or current is detected. The class moreover allows for an external actor to set a positive or negative impulse in the computation, for example to synchronize it with its counterpart motor. The class is instantiated with the board port mappings, enabling its re-usability.
MotorsHubController	The class implements the control code to actuate two motors in an adaptive synchronized way. It extends the *CommandParser* and defines the applicable commands that drive the actuators. Furthermore, the class publishes the internal state of the Motors, their sensors and their states. The class cam monitor the rotational speed difference of the motors and adapts them in order to maintain the desired synchronized or differential motion of the left and right in-wheel motor hubs.

Single Page Web Application

The Agrofelis motor hub driver establishes a WebSocket server that implements a message protocol for reflecting in a standardized way the indicator data of the module and controlling its exposed commands. Consequently, multiple agents can tap into this channel and operate its functionality. One such "agent" has been implemented in the form of a client side web application. The HTML-based web application follows a simple pattern where HTML elements are tagged to correspond with specific commands. For instance, an input element might correspond to command 3, which controls speed. Moreover, by simply setting the class of an input element to "sensor", it will automatically reflect the value received from the motor hub. A common JavaScript file parses the HTML structure and, with very few annotations, reflects motor hub sensor values in the HTML. Likewise, it listens for input modifications and submits the related command to the module.

Each of the motor hub drivers can be accessed also via lightweight standalone web applications, enabling to review the internal state of the module as well as to control it. The two respective applications, differentiating mostly to specify which sensor identifiers they should tap into, are available in the following paths:

- MotorsHubControllerBack.html
- MotorsHubControllerFront.html

Both of the HTML files utilise the following assets:

File	Description
styles.css	Defines the css styles of the web application.
motorsHubController.js	Establishes a web socket connection with the related IP of the module. Parses the HTML to identify the related sensors and actuators. Listens for interface changes as well as for websocket messages and according reflects or submits the related information.
agrofelis_logo_white_web.svg	The scalable vector graphic logo of the project.
jquery.min.js	minified js library dependency JQuery.

Special care has been devoted so the setup and code is very lightweight, clean and straightforward in order to be easily modifiable, assisting the rapid prototyping.

Unificator

The motors hub driver application runtime information and its modules can also be accessed and controlled via the Agrofelis Unificator software, which is able to unify multiple Agrofelis modules connected via various interfaces, including Serial, WiFi, Web-sockets, and USB. Lightweight single-page web applications can easily map, bind and monitor the internal state of two motor hub drivers and their sensors, as well as other modules as seen by the following screenshot.

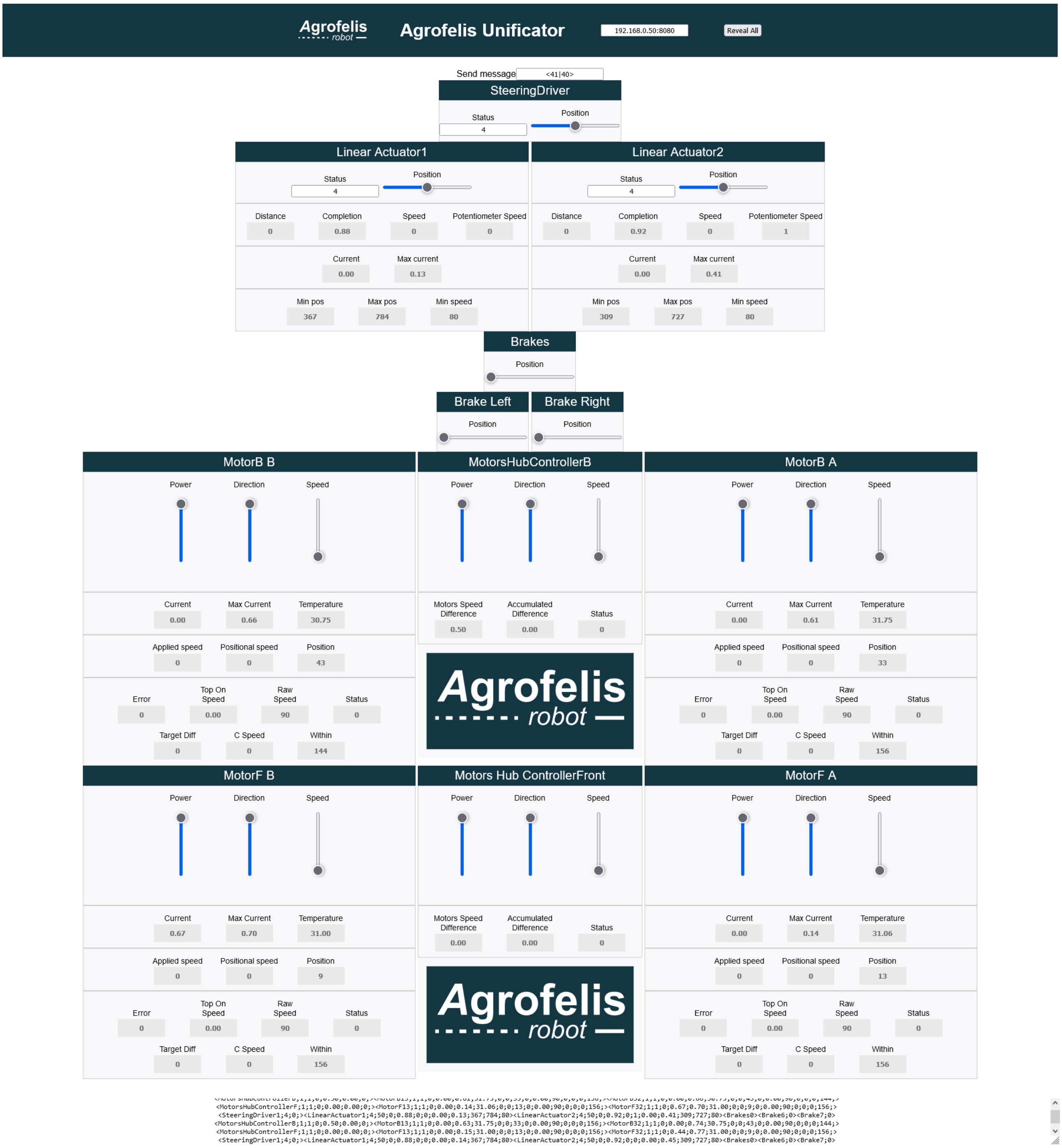


Figure 34: Agrofelis Unificator

For further details on the Agrofelis Unificator software, please refer to the related chapter in the Agrofelis documentation.

Power Distribution Module

The module receives power from the *power distribution module*, which is documented in the relevant chapter of the documentation. [https://github.com/meltoner/agrofelis/tree/main/components/vehicle-power#switchable-power-points]

Motors Hub Components and Indicative Suppliers

In the pursuit of crafting a resilient and high-performing robot, the selection of reliable suppliers for essential components holds profound significance. We present a comprehensive overview of the suppliers who have contributed to our robot-building endeavor. This compilation of essential supplier information not only showcases the parts acquired and supplier names but also includes product types and URLs for direct reference, along with pertinent notes where necessary. Furthermore, the table presents information about quantities, VAT-inclusive prices, and subtotals, all denominated in euros (€), allowing for a detailed financial analysis. Keep in mind that this list of suppliers serves as an illustrative guide, aimed primarily at providing details about the requisite components essential for the construction of each module.

Motors hub controller module

The following table provides an overview of indicative suppliers associated with various parts described in the motors hub controller module.

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#1	Copper board	PCB board	GRobotronics	0.25	9.90	2.48	Base Component
#2	A4 paper	Paper	Bitprice	1	12.00	12.00	Base Component
#3	ESP32 with 38 pins	Development Board	AliExpress	1	3.59	3.59	-
#4	20-pin female headers	Female Pin Header Kit	Nettop	1	9.90	9.90	Base Component
#5	2-pin female header	Female Pin Header Kit	Nettop	0	9.90	0.00	Shared Resource
#6	4-pin female header	Female Pin Header Kit	Nettop	0	9.90	0.00	Shared Resource
#7	2-pin JST male connector	XH Connector Kit	GRobotronics	1	6.20	6.20	Base Component
#8	3-pin JST male and female connector	XH Connector Kit	GRobotronics	0	6.20	0.00	Shared Resource
#9	Green screw terminal 2P	Screw Terminal	GRobotronics	2	0.30	0.60	-
#10	Two 5-wire ribbon cable	Ribbon cable 28AWG	GRobotronics	0.50	1.00	0.50	Shared Resource
#11	5-pin female headers	Female Pin Header Kit	Nettop	0	9.90	0.00	Shared Resource
#12	One 3-wire ribbon cable	Ribbon cable 28AWG	GRobotronics	0.15	1.00	0.15	Shared Resource
#13	DS18B20 temperature sensors	DS18B20 Temperature Sensor	Nettop	2	2.20	4.40	-
#14	Wire pieces for PCB bridges	Ribbon cable 28AWG	GRobotronics	0.05	1.00	0.05	Shared Resource
#15	8 cm case cooler	Case Cooler	MG Manager	1	2.83	2.83	-
#17	Black and red wire	Black-red wire	GRobotronics	1	8.00	8.00	Base Component

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
	Green screw terminal 2P	Screw Terminal	GRobotronics	2	0.30	0.60	-
	Connectors	Standoff, Bolts & Nuts Kit	GRobotronics	1	4.90	4.90	-
#18	Glue gun	Hot Glue Stick	GRobotronics	1	0.40	0.40	-
#19	In-House Developed Software	Dual Motor Driver Software	In-House	1	0.00	0.00	-
Total						**56.60**	

So, the cost for manufacturing the motors hub controller, excluding expenses related to shipping and assembly, amounts to approximately **56** euros.

Motors hub power module

The subsequent table presents indicative suppliers for the necessary components detailed within the motors hub power module.

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#1	Copper board	PCB board	GRobotronics	0.50	9.90	4.95	Shared Resource
#2	A4 paper	Paper	Bitprice	0	12.00	0.00	Shared Resource
#3	3V SHG relay 6Pin	Relay	Hellas Digital	2	0.50	1.00	-
#4	12V car relay 20A	Microrele	Soulis Niaos	1	6.00	6.00	-
#5	ACS712 20A current sensor module	Current Sensor	AliExpress	1	1.02	1.02	-
#6	5-pin male header	Male Pin Header	Hellas Digital	1	0.24	0.24	Base Component
#7	Green screw terminal 2P	Screw Terminal	GRobotronics	1	0.30	0.30	-
#8	Small wire for PCB	Ribbon cable 28AWG	GRobotronics	0.05	1.00	0.05	Shared Resource
#9	3-pin male header	Male Pin Header	Hellas Digital	0	0.24	0.00	Shared Resource
#10	4 cm high current wire	Black-red wire	GRobotronics	0	8.00	0.00	Shared Resource
#11	6.2 mm female connector	Crimp Wire Connectors	Soulis Niaos	1	0.20	0.20	
#12	Glue stick	Hot Glue Stick	GRobotronics	1	0.40	0.40	-
#13	1A 40V Schottky Diode	Schottky Diode	Hellas Digital	1	0.08	0.08	-
Total						**14.24**	

In terms of fabricating the motor hub power driver, the overall cost, excluding shipping and assembly expenses, sums to around **14** euros.

Motors hub ADAC module

Finally, the ensuing table outlines the components and coresponding vendors of the motors hub ADAC module.

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#1	Copper board	PCB board	GRobotronics	0.50	9.90	2.48	Shared Resource
#2	A4 paper	Paper	Bitprice	0	12.00	0.00	Shared Resource
#3	MCP3008 8-Channel 10-Bit ADC	Microcontroller	Hellas Digital	1	5.87	5.87	-
#4	4-channel I2C-safe Bi-directional	Level Converter	GRobotronics	1	4.90	4.90	-
#5	7-pin ribbon cable	Ribbon cable 28AWG	GRobotronics	1	0.60	0.60	-
#6	4-pin male header	Male Pin Header	Hellas Digital	0	0.24	0.00	Shared Resource
#7	8-pin female header	Female Pin Header Kit	Hellas Digital	1	0.20	0.04	Base Component
#8	One wire cable	Ribbon cable 28AWG	GRobotronics	1	0.60	0.60	-
#9	Glue stick	Hot Melt Glue Stick	GRobotronics	1	4.00	4.00	-
Total						**18.49**	

So, the estimated cost for producing the motor hub ADAC amounts to approximately **18** euros, excluding shipping and assembly charges.

Cost estimation overview

This section outlines the indicative costs associated with constructing the Agrofelis motors hub driver module. These figures are derived from estimated costs per item discussed in the indicative suppliers section, encompassing a diverse array of components crucial to the motor hub driver's assembly. It is important to note that the cost estimation provided in this section incorporates applicable taxes. However, it is crucial to acknowledge that this estimation serves as a preliminary assessment and is subject to potential variations.

The values provided here are based on information gathered from indicative suppliers and are intended to provide a rough estimate of the project's financial requirements. In this estimation, we have focused solely on the intrinsic value of each component and have excluded supplementary expenses such as transportation, customs clearance, and unforeseen charges. These figures are the initial step in budget assessment and lay the foundation for more detailed financial planning.

The table showcased below provides a detailed breakdown of components and their indicative costs, enhancing comprehension for informed decision-making and budget formulation.

Construction Part	Sub-Total (€)
Motors hub controller	56.60
Motors hub power driver	14.24
Motors hub ADAC	18.49
Grand Total	**89.33**

Consequently, we observe that the total manufacturing cost for the motor hub controller, power driver, and ADAC is approximately **90** euros, exclusive of shipping and assembly costs.

Conclusion

The rationale of the module, its sub components and their elements were elaborated. Photos outlining details of the different phases of the manufacturing process are provided. Source code files, schematics, instructions and printouts to reconstruct the Agrofelis motors hub driver module have been documented.

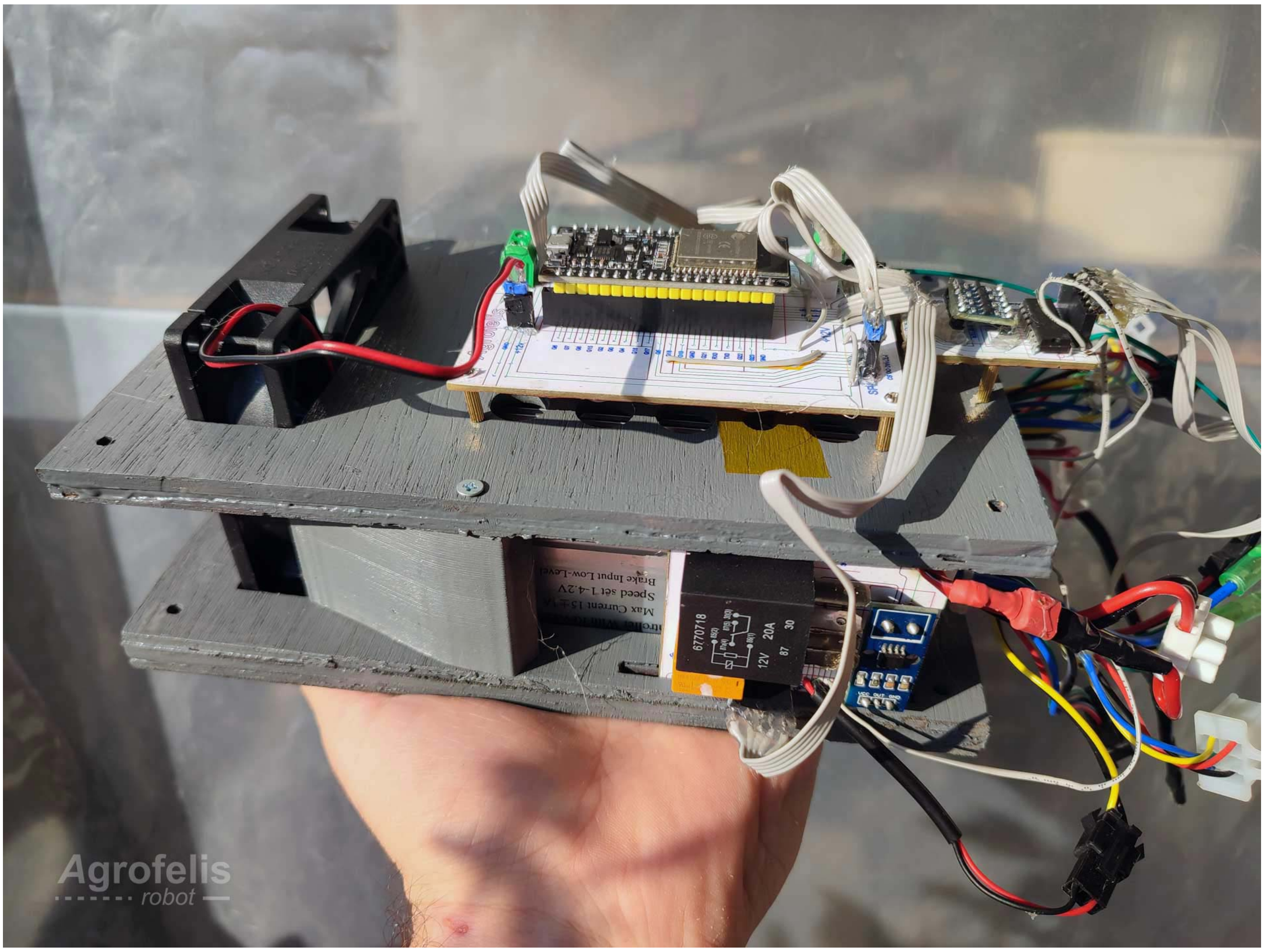


Figure 35: Fabricated Motors hub driver

End of document

3D Lidar Front Sensors Design and Fabrication

Documentation

Agrofelis

Document created on 2023-10-09 04:58:41

Abstract

This document details the creation of the front sensors module, which is used to install a 3D Lidar mount on the Agrofelis robot, enabling it to have spatial awareness of its surroundings. The module comprises an ESP32, an ESP32 Terminal Adapter, a Servo, a Lidar, an MPU and a GPS sensor. The ESP32's primary role is to process Lidar serial data, gather motion sensor and GPS data and pass their information over the USB bus. The module facilitates the tilting of the 2D Lidar to capture multiple planes of 360-degree coverage , effectively creating a spherical 3D view of its surroundings. The rationale behind the module, its schematics, the manufacturing process, the software controlling the module and reflecting its information, as well as a Lidar data analysis tool developed, are all discussed. The document concludes with a list of the components used and indicative suppliers, aiding in the replication of the module.

Contents

Introduction

Equipping a robot with the ability to sense its surroundings enables a profound range of functionalities. Apart from being able to generate detailed 3D maps of the world, perform localization and determine the trajectory of the vehicle, it can also serve as a copilot, preventing movements that would lead to a collision or adjusting robot movements to avoid them. Furthermore, the ability to create 3D maps of the world, record all controlled data and the trajectory of the vehicle, establishes the capability for automation via recording and replaying sequences of moves performed in the field.

The generated 3D maps can be indexed and recalled based on GPS truncated coordinates, compared to known maps, or set by the user. The motion processing unit (MPU) is attached directly beneath the Lidar and tilts with it. Its data can be used to derive the absolute orientation of the vehicle and the true point cloud when navigating on an uneven terrain.

The following figure depicts how different tilting azimouths and the internal polar rotation of the Lidar translate to x, y, and z coordinates.

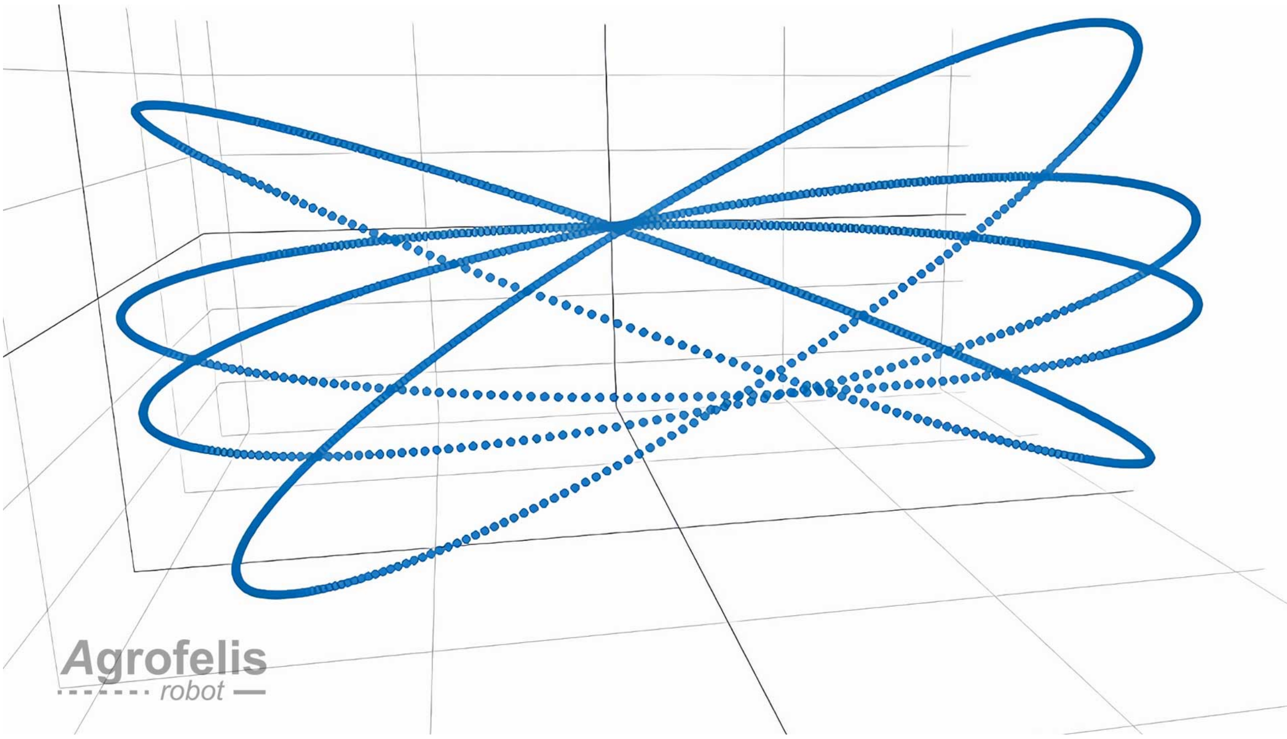


Figure 1: planes

In the subsequent sections, the Agrofelis front sensors 3D Lidar module design and fabrication is documented.

Front Sensors Module

The purpose of this module is to create a reusable module that can be installed on the front and/or back of the robot to provide complete coverage of its surroundings. Although the module is not neccessary for the operation of the Agrofelis robot, it renders it capable to navigate through the world and perform autonomous functions, as well as adapt its motor's dynamic ranges efficiently due to the additional data modalities that can be utilised. The module's prototype utilizes a terminal shield, making it easy to extend its functionality with other sensors like CO2 or humidity sensors without altering its core structure. Although the selected Lidar's internals are already enclosed in a dust and waterproof casing, further work could focus on extending the prototype to provide additional structural protection.

The following figure depicts an overview of the vehicle with the relevant module installed on the front side.

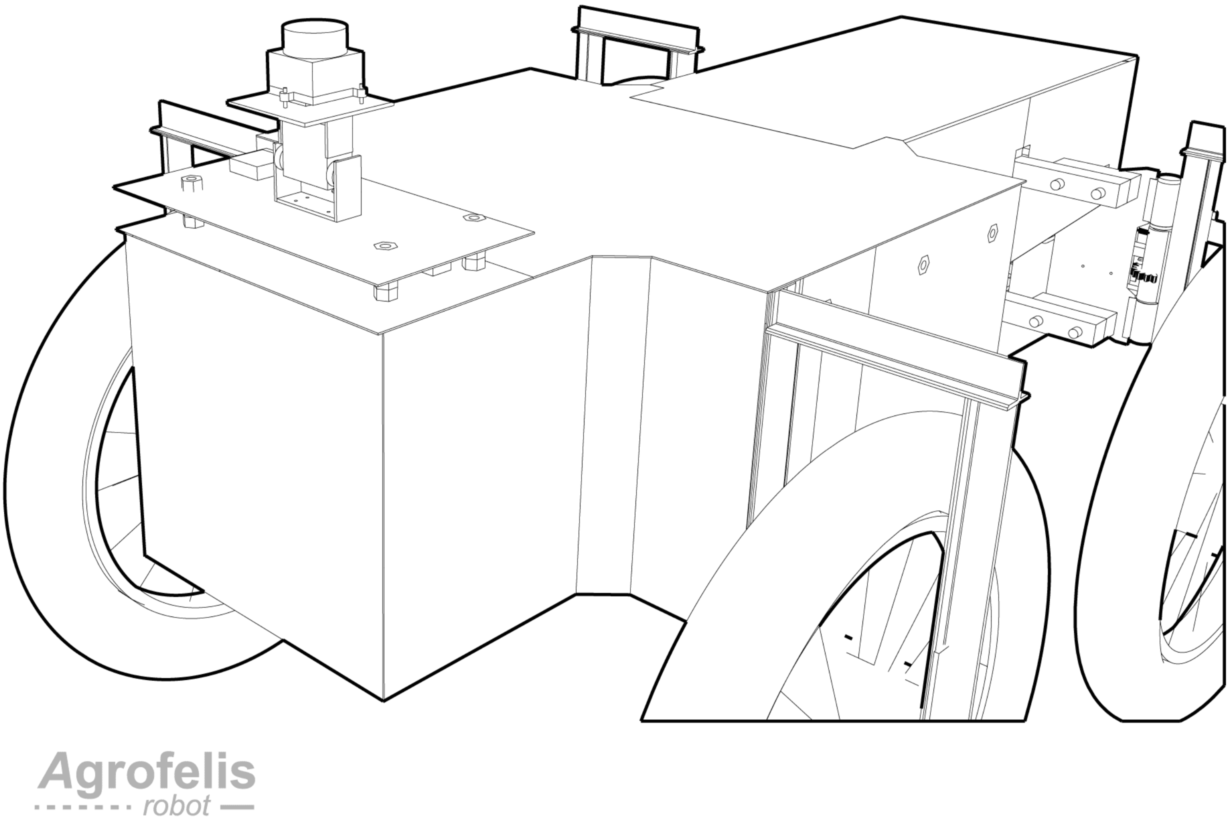


Figure 2: lidar overview

To construct this module, a plate is attached to the frame cover's sockets using long bolts with nuts adjusting its height and securing the frame covers. Within the enclosure formed by the two iron plates, the electronics and power/data connection socket are established. On the top side of the plate, a GPS antenna is installed, along with a servo actuator positioned in the middle. A 70mm x 70mm piece of plywood is affixed to the top bracket of the servo. On top side of the plywood plate, the MPU (gyroscope and magnetometer) is installed. Finally, the Lidar is attached on top of the MPU using PCB standoffs and the plate is secured to the servo bracket.

Schematics and Fabrication

In this section, the schematics of the module along with photographs taken during the fabrication process are provided.

The following figure encodes the key dimensions of the module.

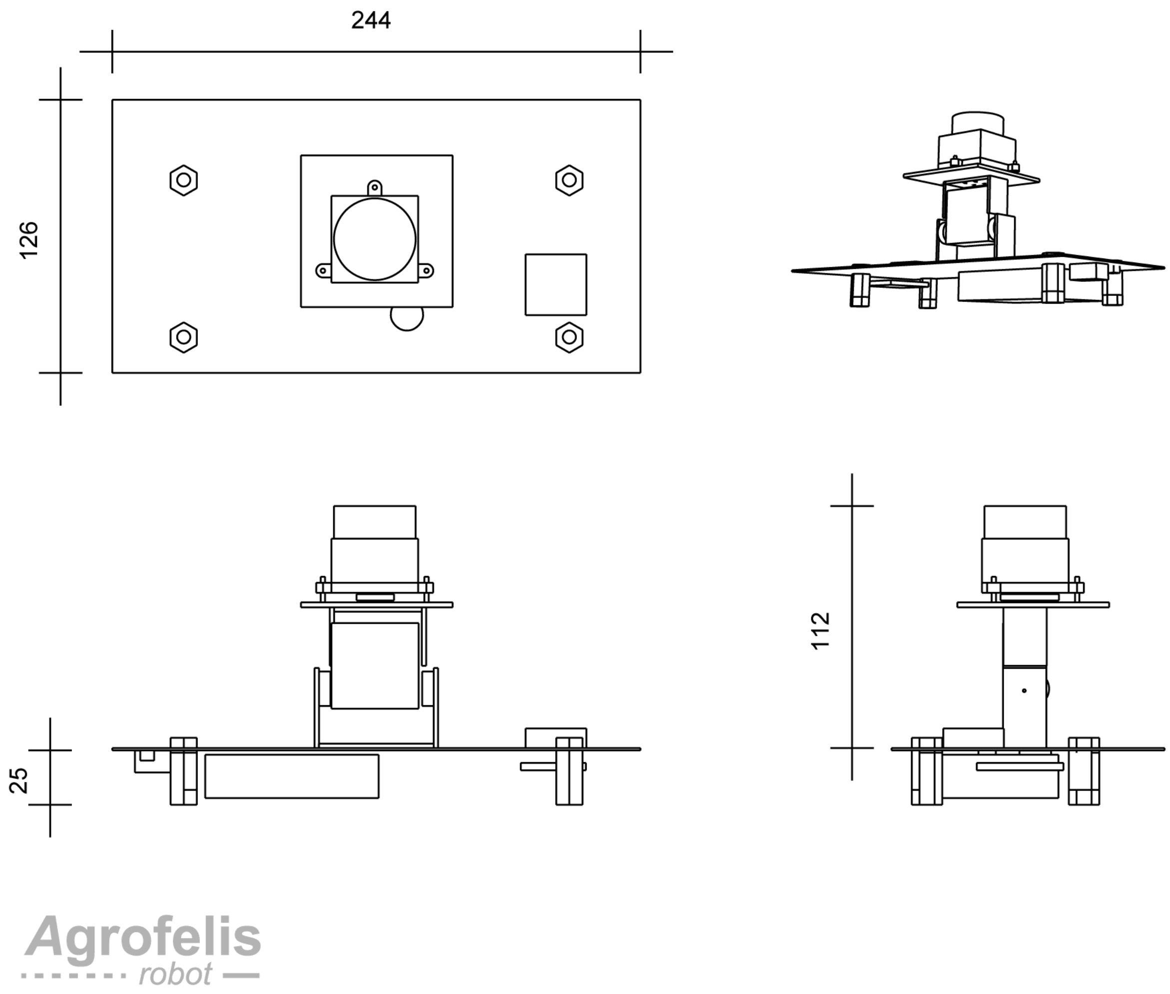


Figure 3: Lidar dimensions

The consequent diagram enumerates the module’s components using an exploded view.

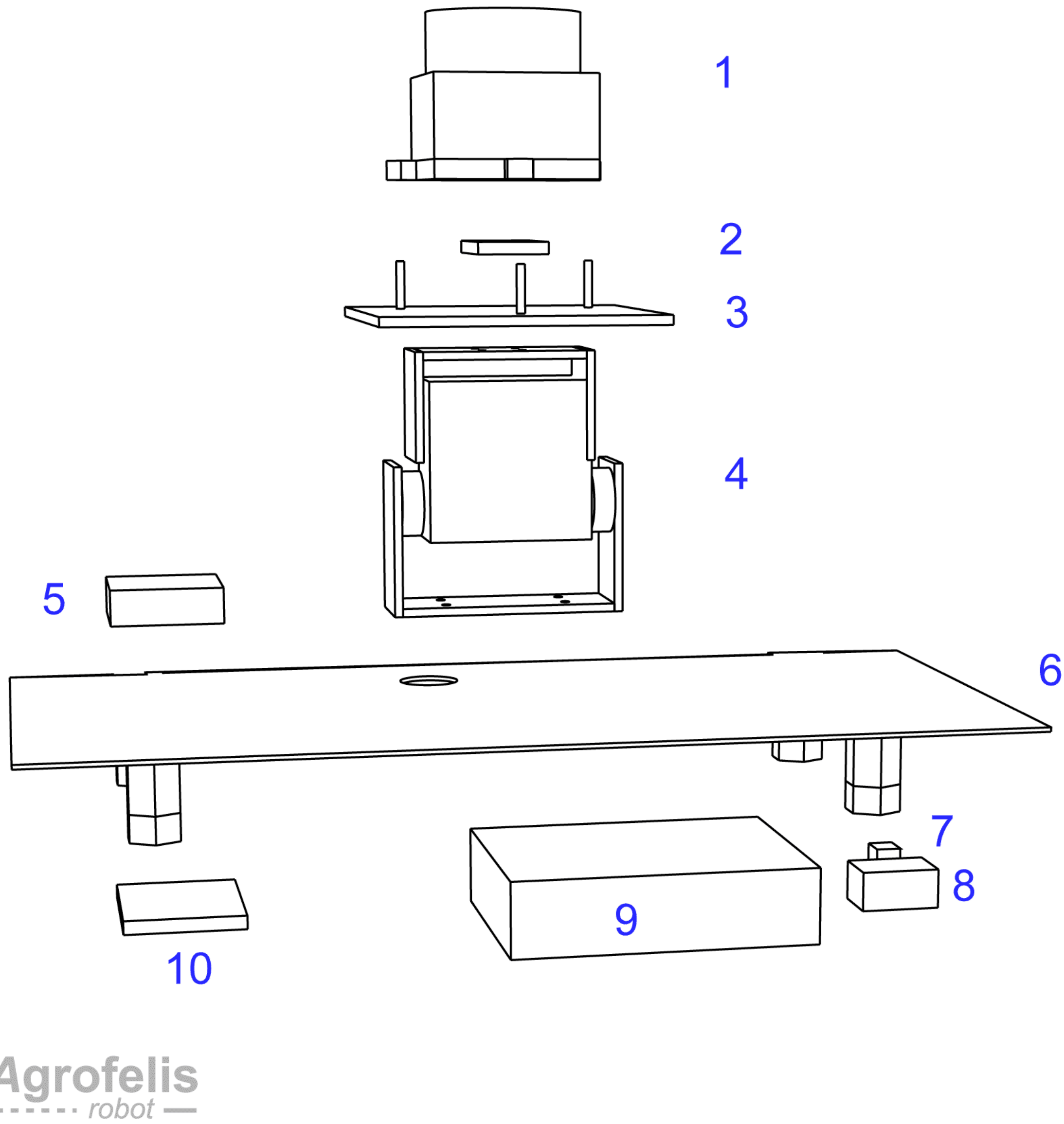


Figure 4: Lidar exploded view

The numbered components correspond to the following items:

1. LD19 Lidar Scanner 360° TOF 12m
2. MPU 9250
3. Plywood Plate
4. Servo RDS3218 20KG 270 Degree
5. GY-NEO6MV2 GPS Module Antenna
6. Iron Sheet (2mm)
7. Data Socket
8. 5V Power Socket
9. ESP32 with 38PIN Terminal Adapter Shield
10. GY-NEO6MV2 GPS PCB

The following photo showcases a piece of iron plate, near the designed dimensions with four drilled holes matching the sockets layout of the related cover of the Agrofelis robot.

Figure 5: plate

In the middle of the plate, four holes following the servo's bracket layout are drilled and the servo's longer bracket is assembled using four bolts and nuts, as illustrated in the following image.

Figure 6: Servo mount

The servo is then mounted on the installed bracket, as shown by the next photograph.

Figure 7: Servo addition

The top bracket of the servo is installed on a 70 mm X 70 mm 4mm plywood plate, as seen in the image below.

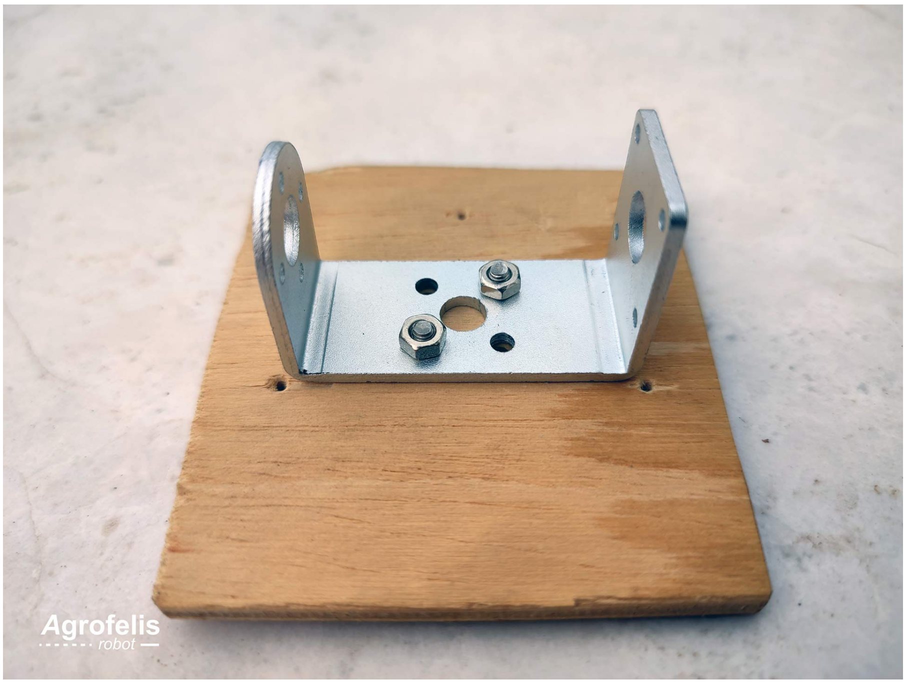


Figure 8: Top bracket

Three thin PCB standoffs are installed on the other side of the plywood plate in its middle, following the Lidar's profile holes.

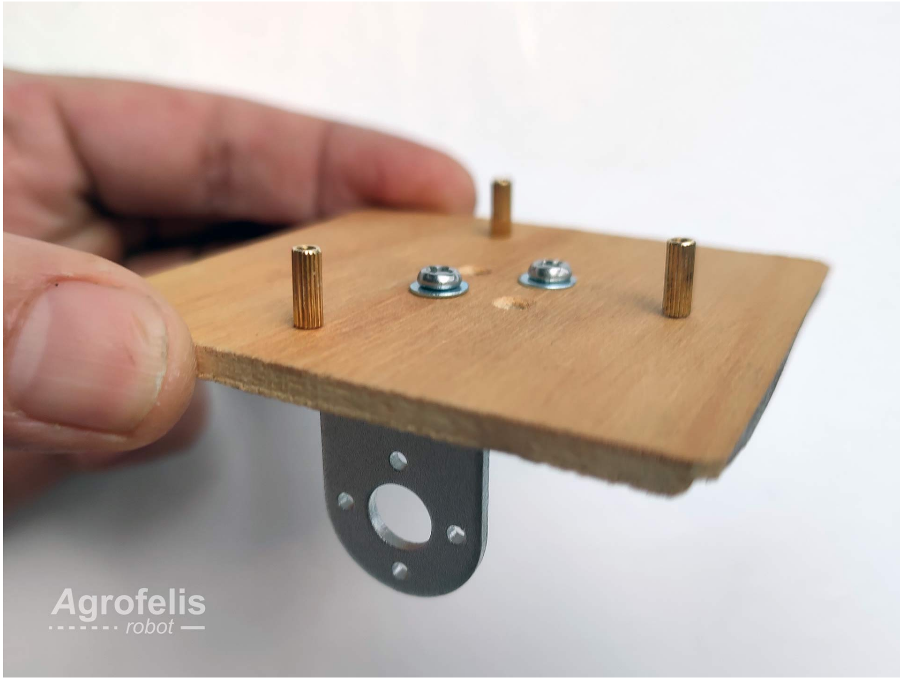


Figure 9: Plate PCB standoff

Within the PCB standoff in the middle of the plate, the MPU 9250 sensor is installed.

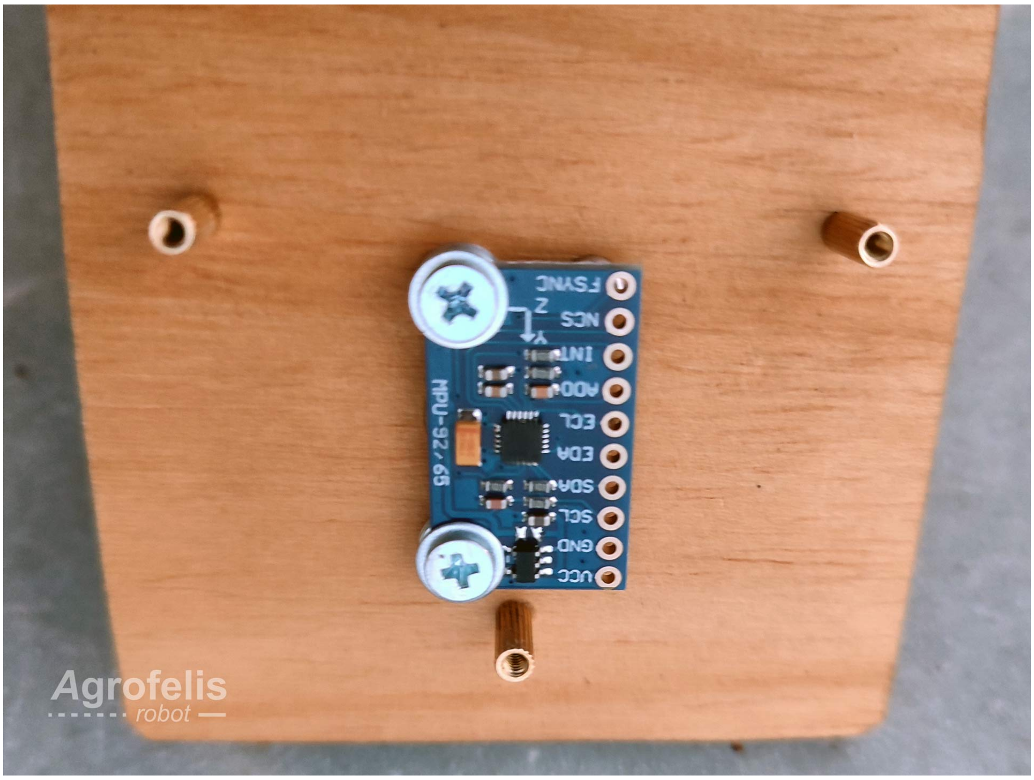


Figure 10: MPU

The module, complete with the plate, servo, plywood plate, MPU, Lidar and connecting cable, is shown in the following photograph.

Figure 11: Assembled

The tilting mechanism of the Lidar via the servo and the installment of the GPS antenna can be seen in the following two images.

Figure 12: tilted-front

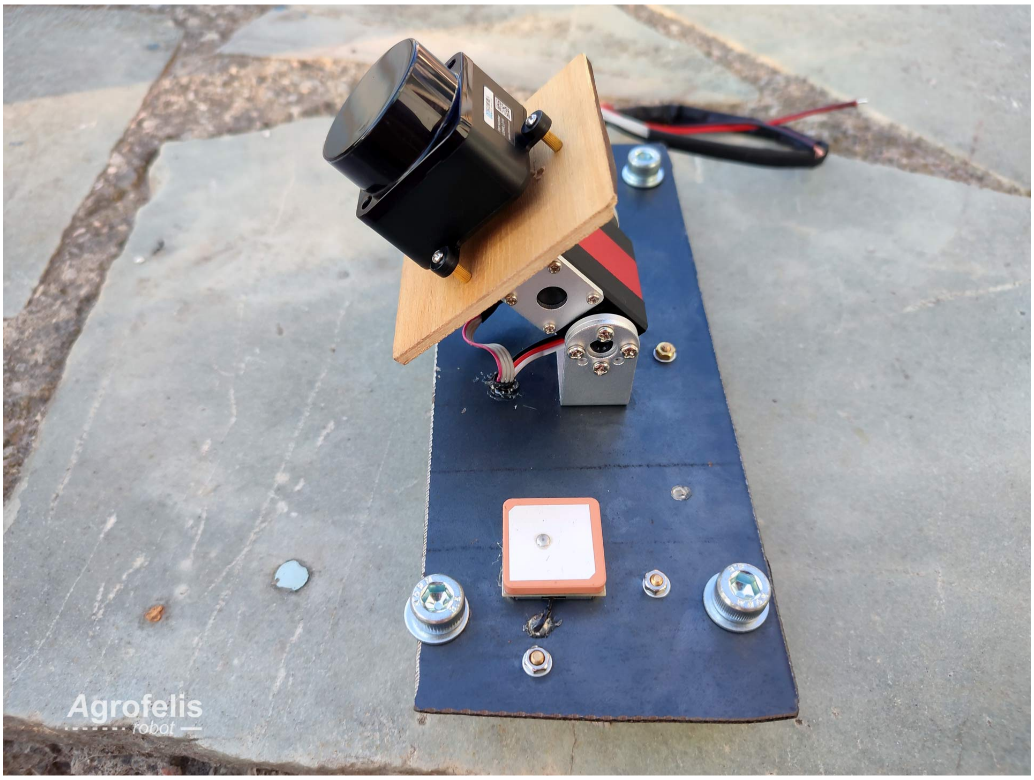


Figure 13: tilted-back

Two types of cables are fabricated in order to connect the module to the Agrofelis robot. The first type provides 5V to power the micro-controller and the servo motor. The second type enables data connectivity using a 3-pin ribbon cable. This second type taps into the USB connection of the ESP32. By cutting a regular USB cable in half and omitting the 5V cable, as the module is already powered, then interfacing the ground, data A and data B cables, a high-throughput wired connection is established all the way to the back of the vehicle's USB hub, which connects to the Jetson Nano. This USB channel was found to be the most robust solution for transferring the high-frequency Lidar data without errors. The two types of cables, along with their sockets installed and grouped using a cable insulation tube, are shown in the following photo

Figure 14: cables

The consequent photo snapshots the fabricated underside of the prototype, illustrating the installed electronics, sensor cable, USB cable hack, sockets and the two types of cables connected to them.

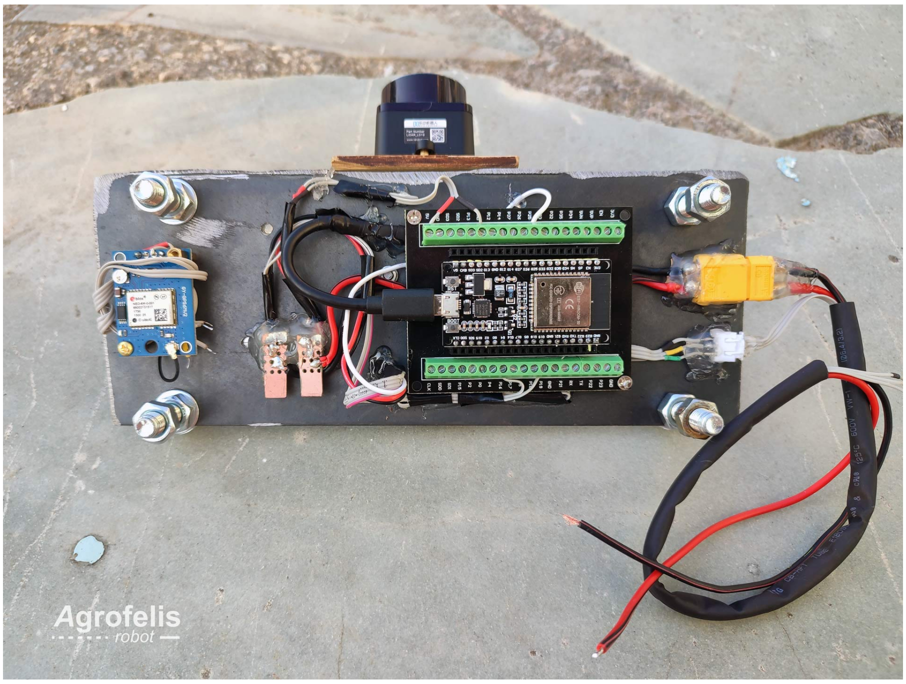


Figure 15: electronics

The next photo shows the fabricated top side of the prototype, presenting the tilting mechanism and the Lidar.

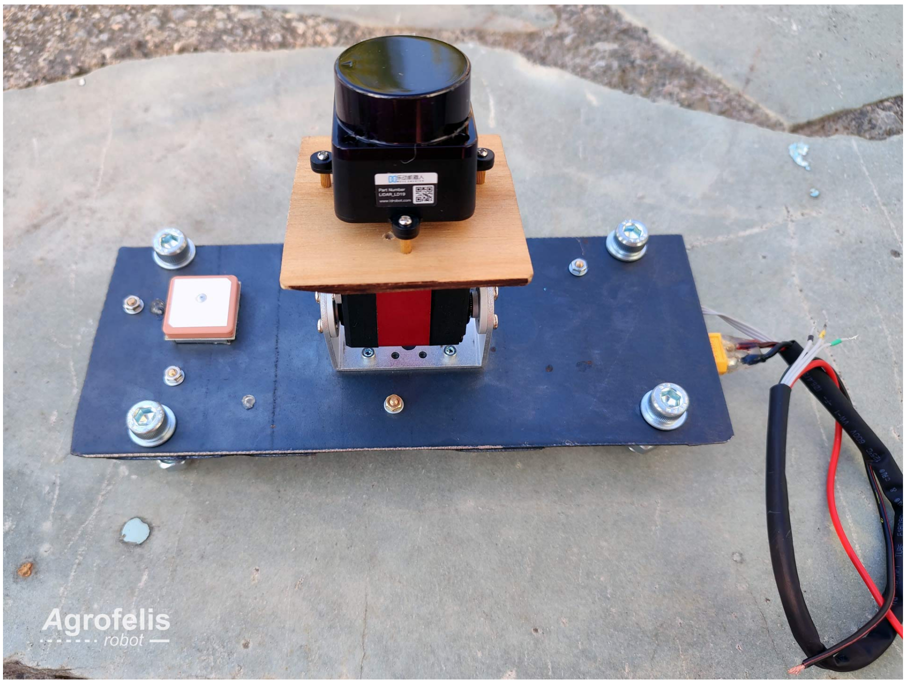


Figure 16: front-view

The following schematic illustrates the designed module attached to the vehicle, alongside the 2 degrees of freedom rotating implement mount.

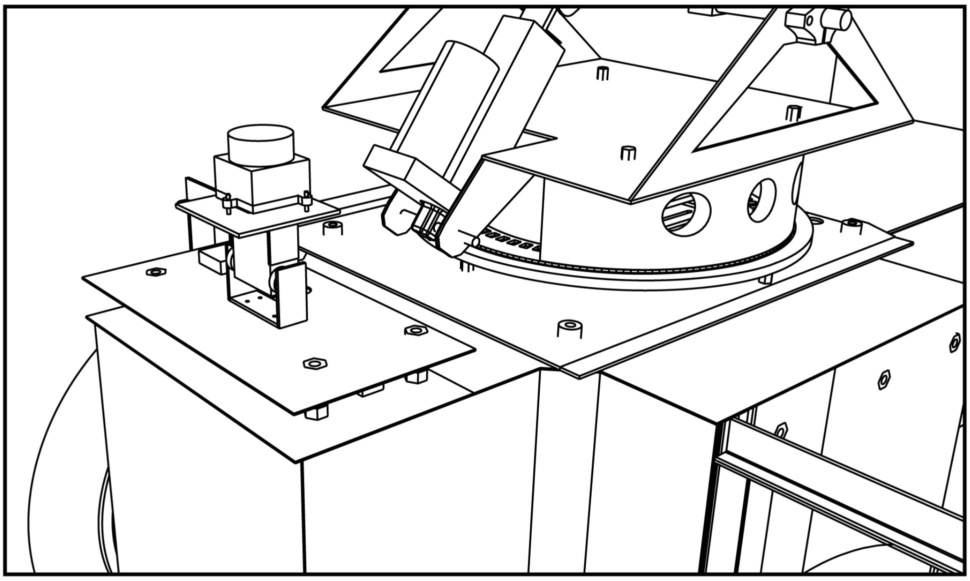


Figure 17: with-rotating-implement

The next photograph shows the energized fabricated module mounted on the Agrofelis Robot.

Figure 18: actual-front-view

A close-up view of the module attached to the vehicle is provided below.

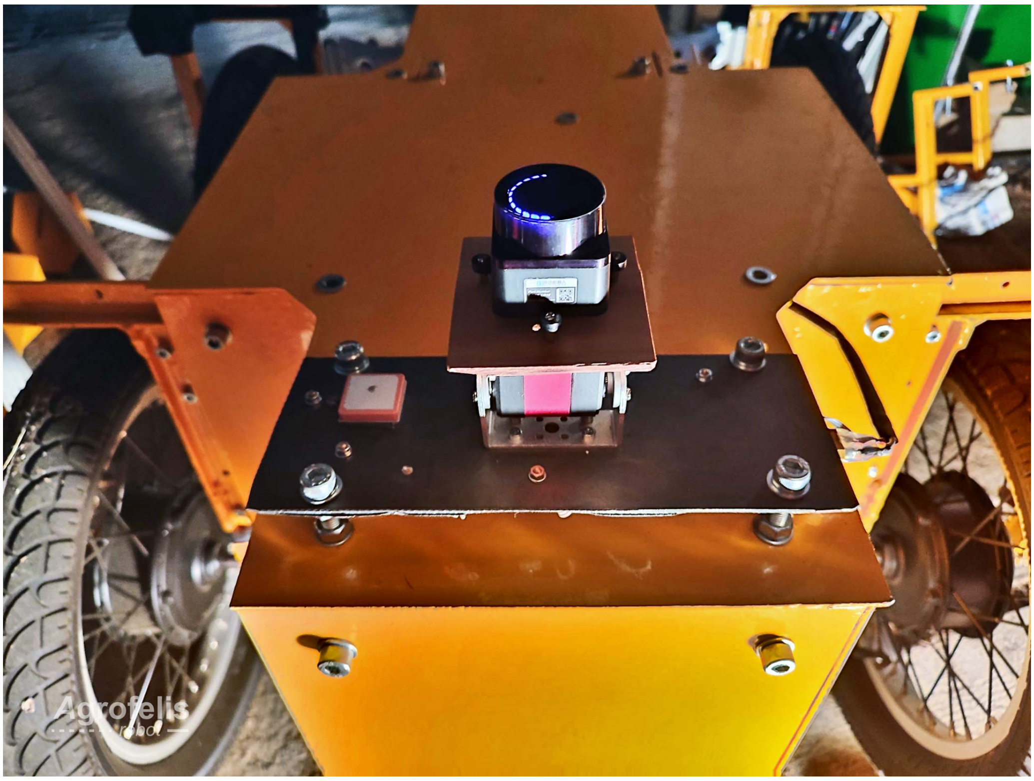


Figure 19: front-view-closeup

Lidar Data

In order to retrieve data from the ESP32 micro-controller, we harnessed the capabilities of the following open-source repository.

- Lidar_LD06_for_Arduino Repository

Although this repository was initially designed to support the LD06 model, its functionality was verified for the LD19 model as well. The Lidar's cable was cut and connected to the Serial2 interface of ESP32 and a pulse-width modulation (PWM) capable GPIO, using the following correspondence.

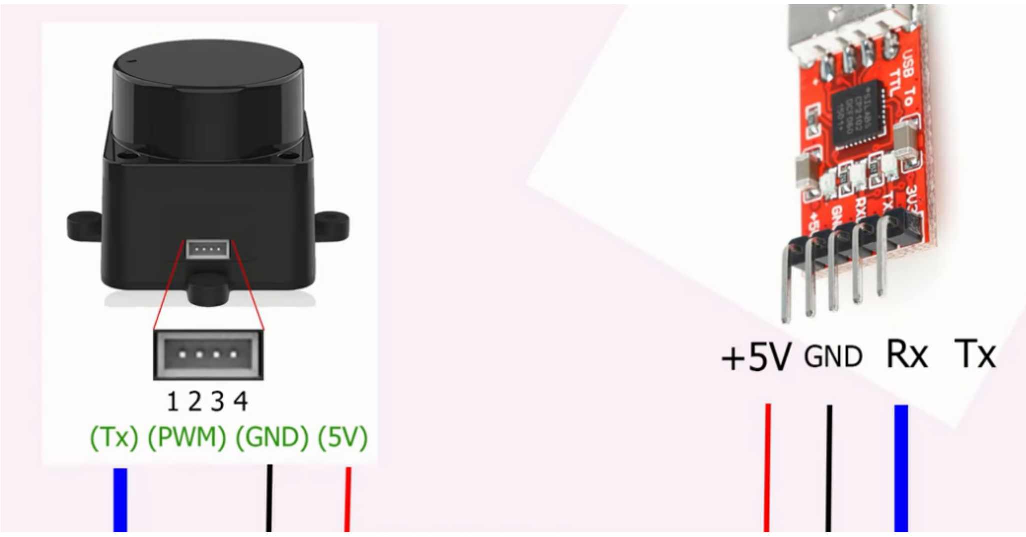


Figure 20: Lidar pin cable correspondence

The data provided by the UART interface are decoded by the library and are converted to angular degrees, distances and confidence levels. The Agrofelis software of the module transmits the first two variables in real-time batches of arcs, and less frequently the applied tilt, the three orientations, the magnetic orientation, the GPS coordinates (longitude and latitude) and the number of satellites locked on to.

The following screenshot captures a glimpse of the data being transmitted and recorded by the Unficator server, encompassing data from both the Lidar and mobility modules.

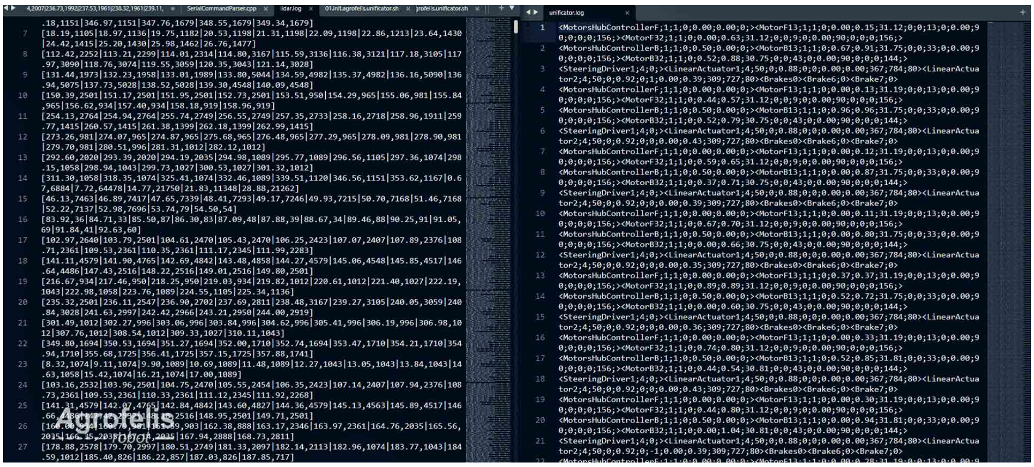


Figure 21: data peek

Agrofelis Front Sensors Software

The software of the module is contained within the src folder. The software is composed of a C++ application developed to reflect and control the internal state of the micro-controller via the USB serial interface.

This *Agrofelis Front Sensors Software* adheres to a common baseline pattern that has been established in nearly all Agrofelis modules. This baseline pattern introduces a "context" class, which is passed to practically all classes as a common ground, enabling instances to exchange information when necessary. The second baseline pattern established refers to the frequency of execution, providing the facilities to trigger specific functionalities at desired intervals. This design consideration accommodates components like the Lidar or gyroscope, which require much more frequent updates compared to components such as GPS or potentiometer sensors. As a bootstrap template, the software provides six different execution frequencies, ranging from 50 milliseconds to 5-second intervals. Using this approach, delays blocking the execution are avoided and the different calls can be organized based on their responsiveness requirements.

Furthermore, the software incorporates straightforward, concrete implementations for elements such as the servo, GPS and Lidar, resulting in a one-to-one mapping between physical hardware elements and their respective software counterparts.

The following table indexes and summarizes the implemented classes of the *Agrofelis Front Sensors Driver Software*.

Class	Description
FrontSenseA.ino	Boots the application, initialises top-level classes and encodes the triggering frequencies of various functional elements.
Context	Provides a common ground for sharing information and encodes the triggering frequencies, helpful functions and a unique identifier of the model.
Invoker	Tracks the execution frequencies so these are called at the right time.
SerialCommandParser	Base class for monitoring and parsing the serial interface data. The class defines the function parsing compact commands of the form <1|1>, where the first parameter corresponds to the applicable action number and the second is an integer value used by the related action.
Servo	Object representing the tilt mechanism actuating a servo motor. The object can be initialised with a limited target range, as much as scan the field without exceeding the physical limits of the mechanism. The class was used with a *TIANKONGRC RDS-8120 20KG ROBOT DIGITAL SERVO*. The class can be instantiated by providing the connected GPIO, the desired range to actuate from the applicable (0-180), which is then mapped to a range of 0 to 100.
CommandParser	Base class for monitoring and parsing the Serial interface. The class defines the function parsing compact commands of the form <1|1>, where the first parameter corresponds to the applicable action number and the second is an integer value used by the related action.
LD06forArduino.ino	See Lidar_LD06_for_Arduino external dependency available on GitHub.
FrontSensorsController	The class extends the "CommandParser", allowing to externally control the tilt servo and the rotational speed of the Lidar.

Lidar Data Analysis and Visualization Software

An exploratory data analysis application was rapidly prototyped as a Shiny R application, facilitating the uploading and analysis of log data captured and packaged by the Unificator server. The application software parses the packages, maintains the Lidar information, extracts the tilt degree and parses the polar coordinate arcs into a data table. The parsed Lidar data are being visualised in two scalable vector graphics (SVG) graphs. The first graph reflects the data as if they were Cartesian coordinates and subsequently projects them using a polar-to-Cartesian coordinate transformation. The application offers the functionality to filter data using a sliding window of 500ms intervals (chunks) and to maintain the 80th percentile of the data, ensuring a focus on nearby surroundings. A screenshot showcasing the Shiny R application for Lidar data analysis, is provided below.

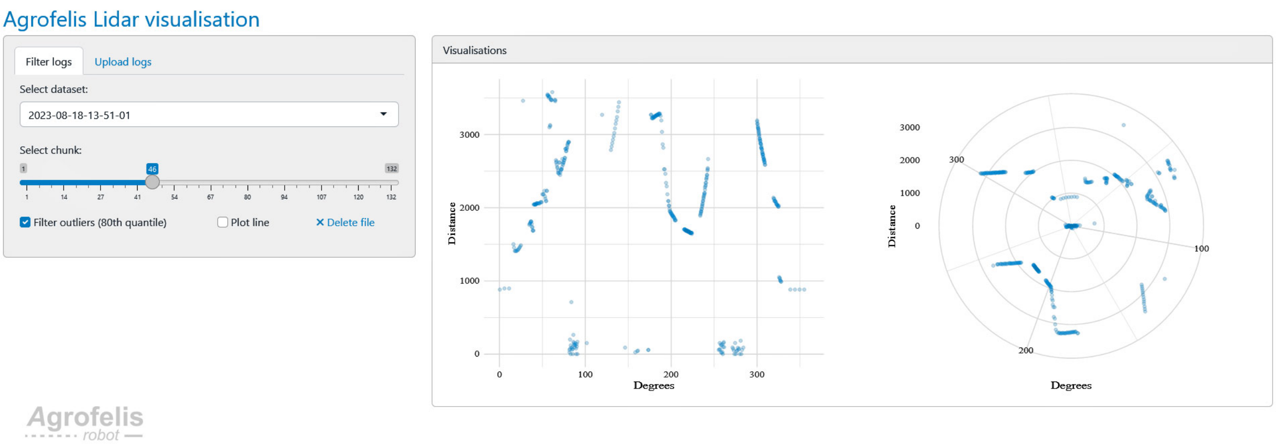


Figure 22: rshiny-app

The source code for the Shiny application can be accessed at the following path:

- Shiny Lidar Analysis

The application's source code comprises four files:

File	Description
global.R	This file loads the R packages used by the program as well as loads the "helpers.R" file.
helpers.R	This file implements file manipulation, Lidar data parsing and data visualisation functions.
ui.R	In this file, the source code defines the layout of the web interface and its input elements.
server.R	Responsible for initializing the server and defining the reactivity of the application.

3D Lidar Front Sensors Components

The following table lists the individual components employed for manufacturing the Agrofelis front sensors Lidar controller. The index table includes moreover the product URLs, the indicative suppliers, as well as unit prices and total cost estimates.

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#1	LD06 12m Range	Lidar	AliExpress	1	119.45	119.45	-
#2	RDS3218 20KG 270 Degree	Servo	NEM	1	19.84	19.84	-
#3	MPU-9250 9DOF 9-axis	MPU	Hellas Digital	1	10.48	10.48	-
#4	NEO-6M GPS Module	GPS	AliExpress	1	2.69	2.69	-
#5	ESP32 38 pin	ESP32	AliExpress	1	3.67	3.67	-
#6	ESP32 38 pin terminal adapter	ESP32	AliExpress	1	2.69	2.69	-
#7	Black and red wire	Black-red wire	GRobotronics	0	8.00	0	Shared
#8	4-wire ribbon cable	Ribbon cable 28AWG	GRobotronics	0	1.00	0	Shared
Total						**158.82**	

The total cost to manufacture the Agrofelis front sensors Lidar controller, excluding shipping and labor cost, amounts to approximately **159** euros.

Conclusion

The document has extensively covered the front sensors module, designed for the implementation of a 3D Lidar mount on the Agrofelis robot. The rationale of the module, its design plans and fabrication steps were documented in a progressive manner. The Lidar data were explained and the software developed for managing the microcontroller and for analyzing the polar data were summarized. The list of the most crucial components, complete with product links, pricing information, along with indicative suppliers for acquiring them, to facilitate the reproduction of this module, were documented. A closing view of the fabricated attachment is presented below.

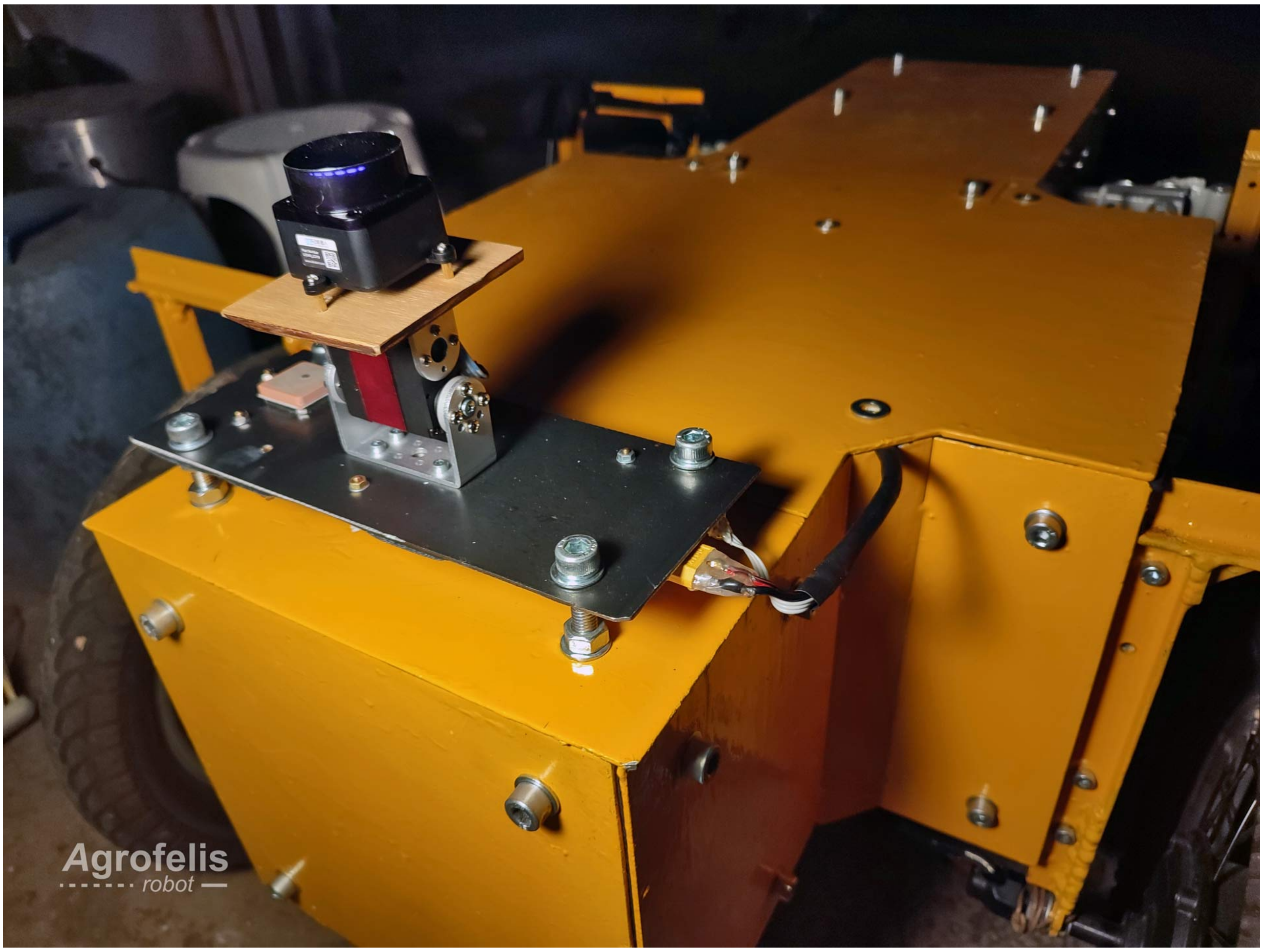


Figure 23: Side view of the Robot with its Lidar

End of document

Two Degrees of Freedom Rotating Implement Mount

Documentation

Agrofelis

Document created on 2023-10-09 05:30:14

Abstract

This document outlines the construction of the Rotating Implement Mount (RIM), a crucial component positioned atop the Agrofelis robot. The RIM's primary function is to enable the use of various implements, such as the thermal fogger featured in the presentation video. The rotation is achieved through the use of a stepper motor that powers the rotation by turning a gear on a turntable, while elevation/depression is achieved with the use of a linear actuator leveraging the mount, thus granting the RIM a two degrees of freedom (2DF) capability for any implement mounted on it. This report covers the rationale behind the module, its schematics, source code files and details of the manufacturing process. The document concludes with a list of the components used and assorted with indicative suppliers, facilitating the replication of the module.

Contents

Introduction

Implements that need to be mounted at the front of the vehicle, such as a grass cutter, must follow the vehicle's orientation. However, for implements placed on the Rotating Implement Mount (RIM), which is located on the top of the vehicle, they are able to orient independently. This feature proves especially useful for various spraying techniques. The RIM is a relatively simple 2DF mechanism, offering the flexibility to use such tools at a low cost.

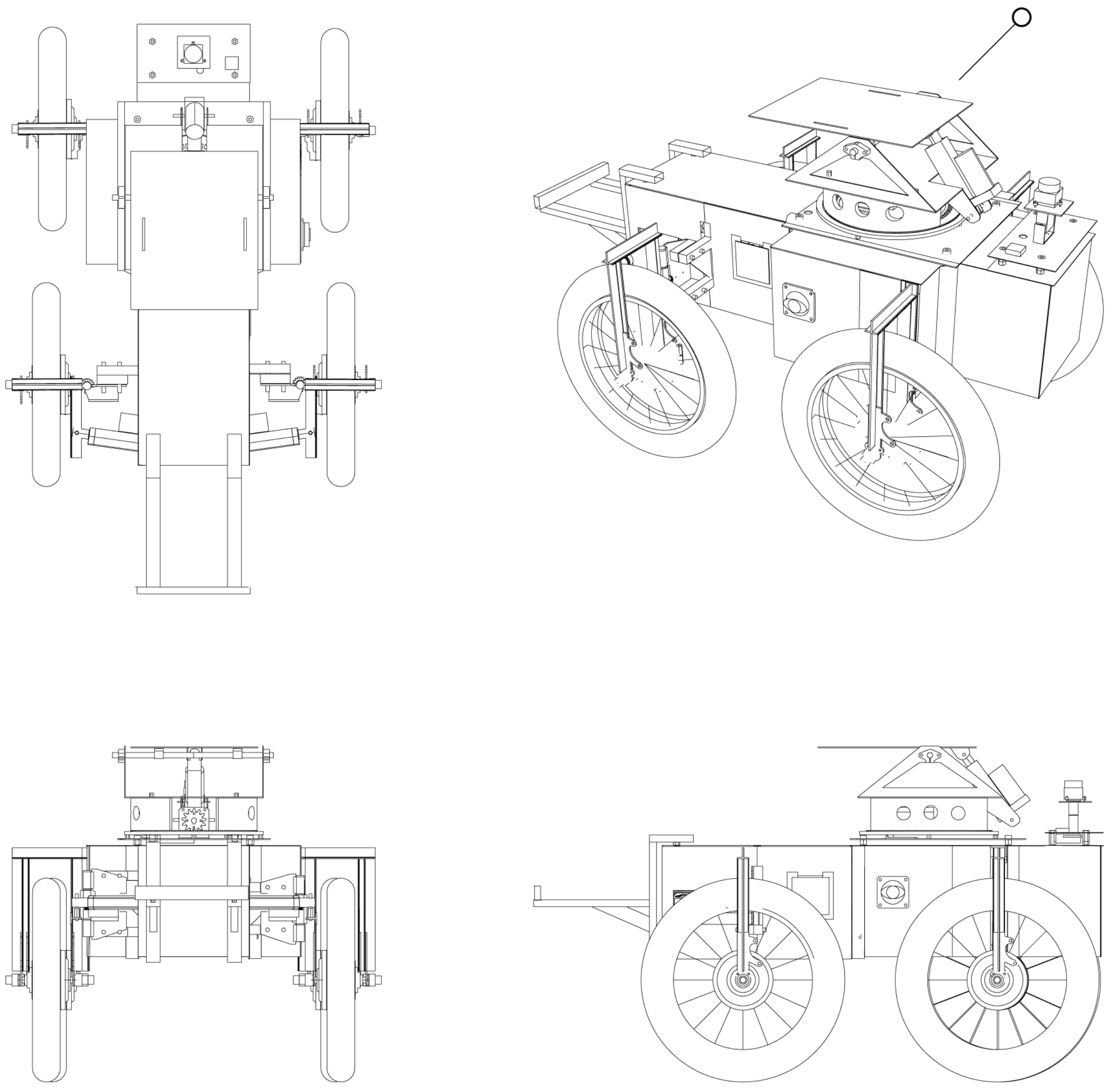


Figure 1: overall view

Implement Mount Module

The bottom part of the module features a 360-degree ball-bearing turntable with an attached horizontal gear disc of 70 laser-cut rectangular holes in which a 13-teeth gear runs and provides the horizontal tilt. The middle part possesses a depression angle of -5 degrees and an elevation angle of +40 degrees, which can be leveraged using the linear actuator, and it enables the vertical tilt. The top part serves as the actual mount surface for attaching implements. Note that the suspension of the mid-part onto the turntable is achieved by using four long screws and two 3D printed plastic arcs supporting the over-structure.

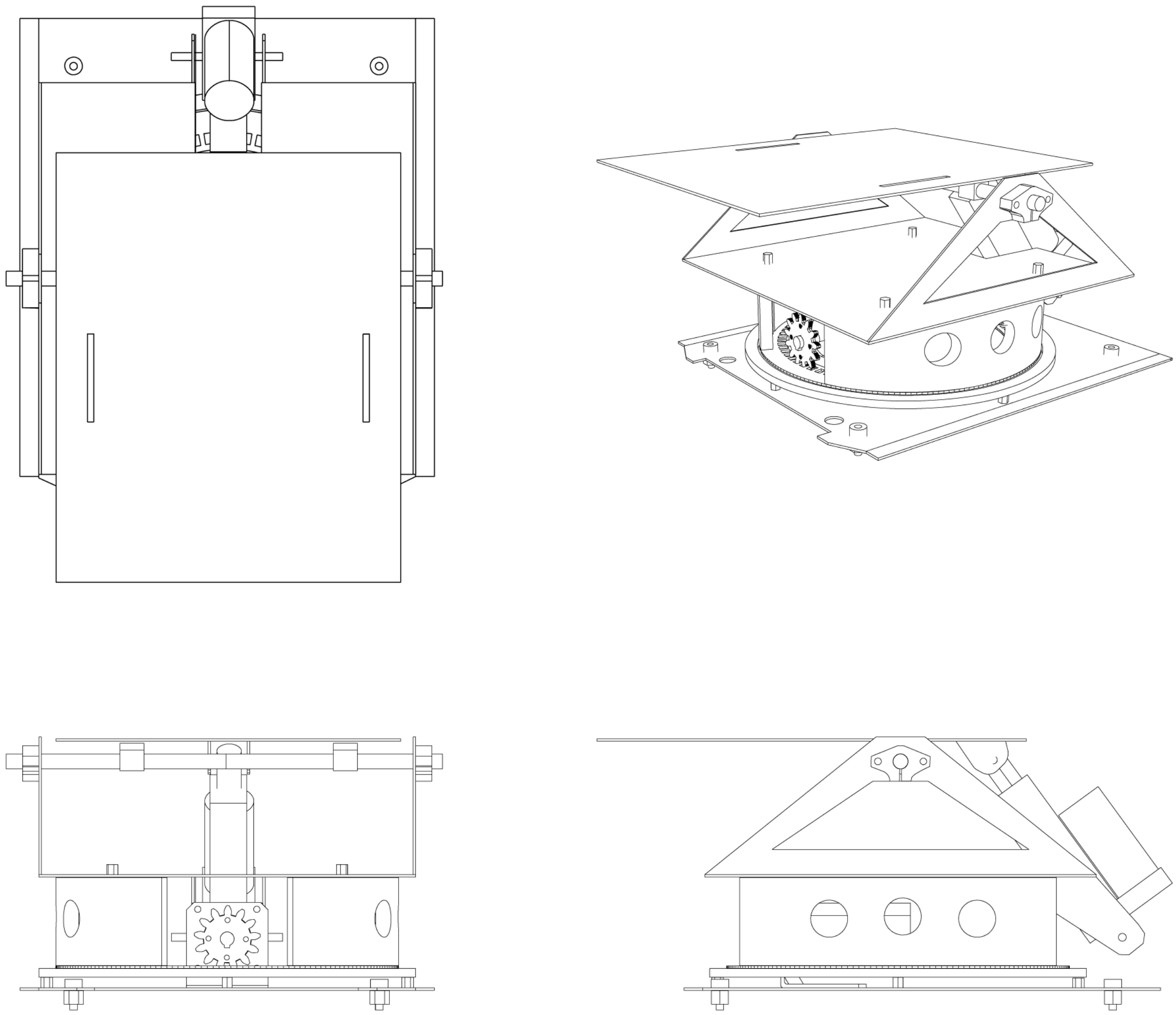


Figure 2: module

The parts of the rotating assembly, alongside with the supporting plastic arcs and the four long screws that link the bottom and mid parts, are visible in the following photo.

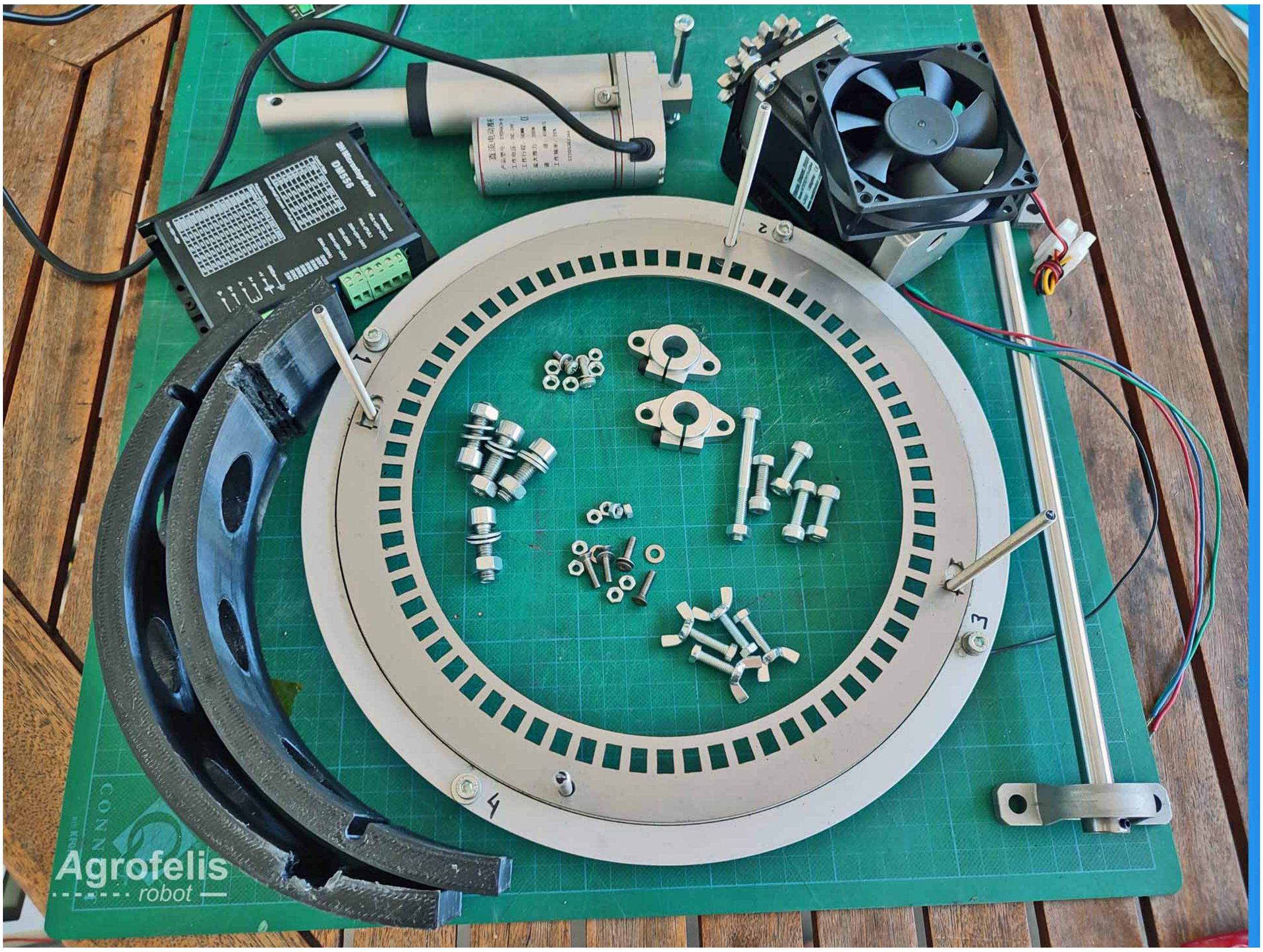


Figure 3: components

An exploded view of the entire mechanism and its functional design details, is presented in the schematic below.

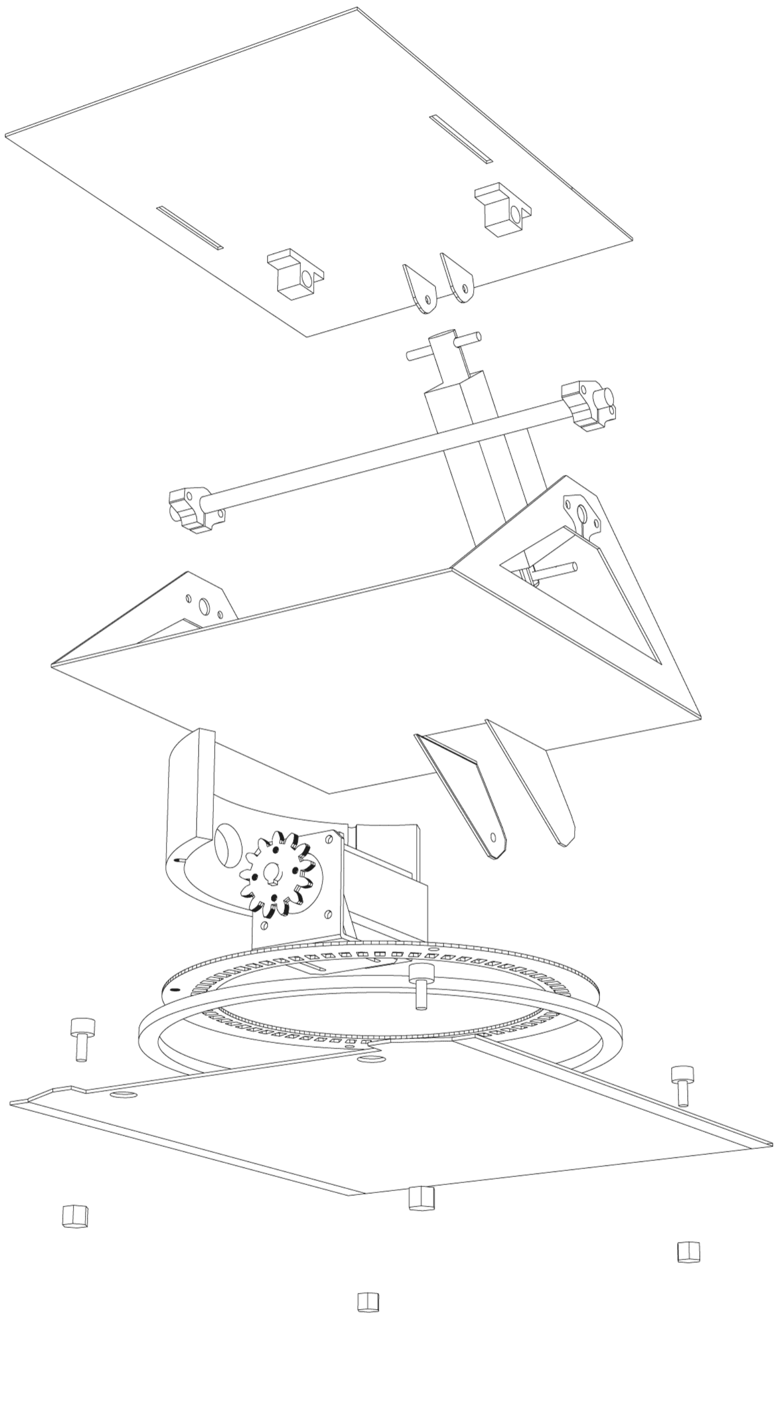


Figure 4: exploded

Furthermore, a lineup of the assembly parts of a decomposed mechanism can be seen in the following schematic.

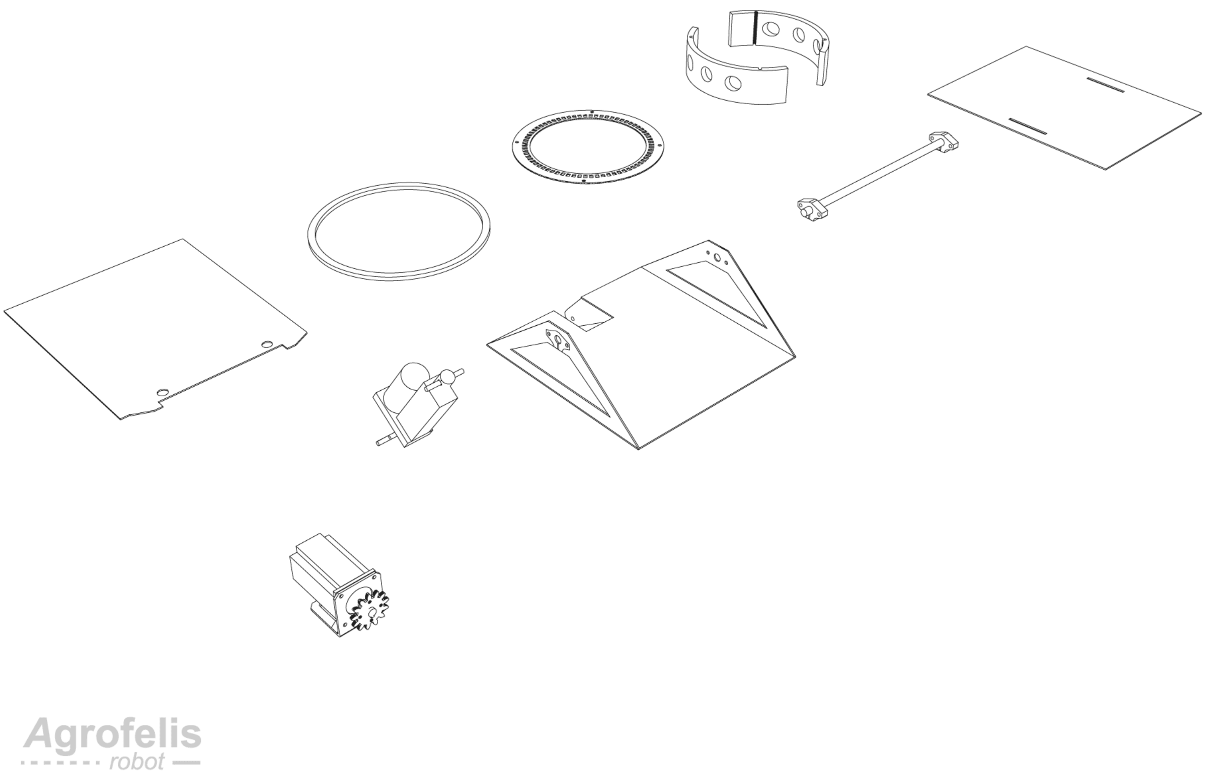


Figure 5: decomposed

The list below enumerates the components of the Rotating Implement Mount (RIM).

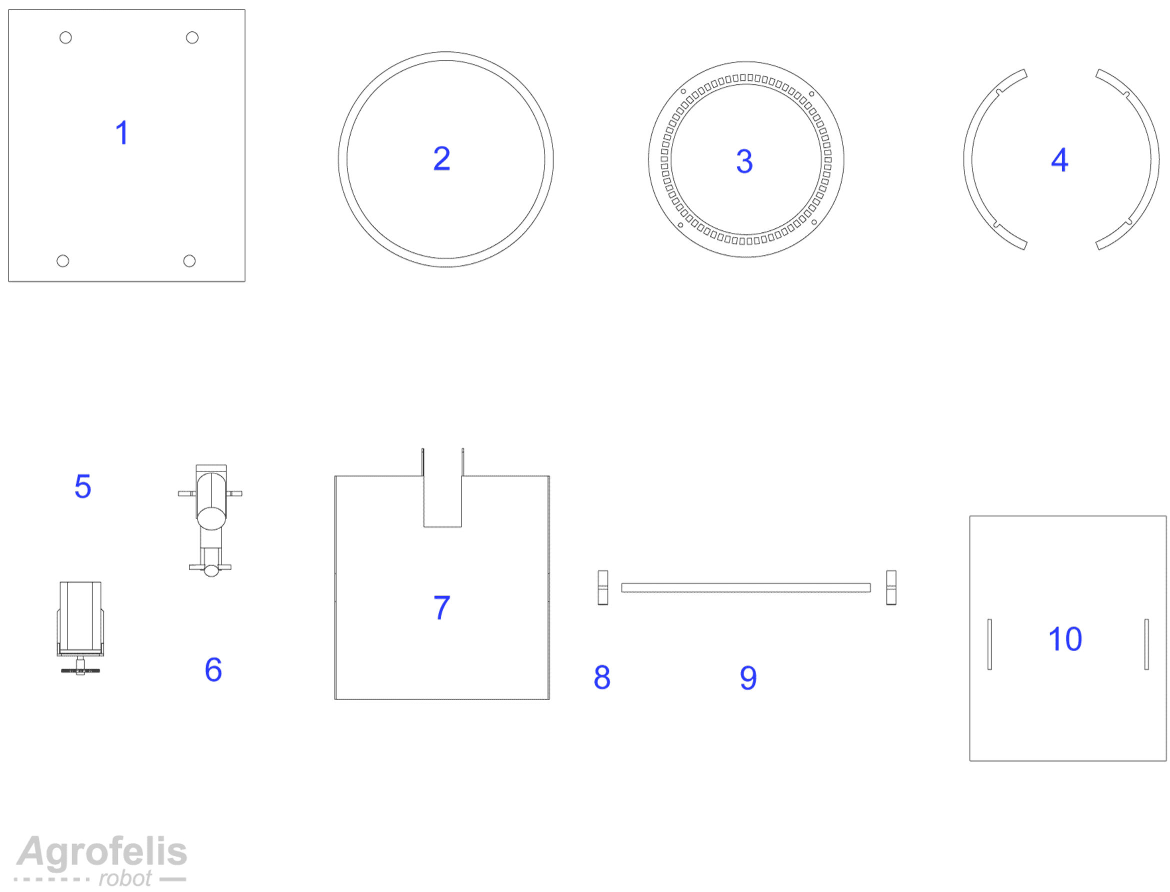


Figure 6: enumerated

1. Bottom Base
2. Ball Bearing Turntable
3. Horizontal Gear Disk with rectangular holes
4. Supporting Plastic Arcs
5. Stepper Motor with Gear
6. Linear Actuator
7. Mid Base
8. Linear Shaft Support Bracket
9. Linear Shaft
10. Top Base

Fabrication Parts

Bottom Base

The dimensions, followed by a fabricated metal sheet base, are presented below.

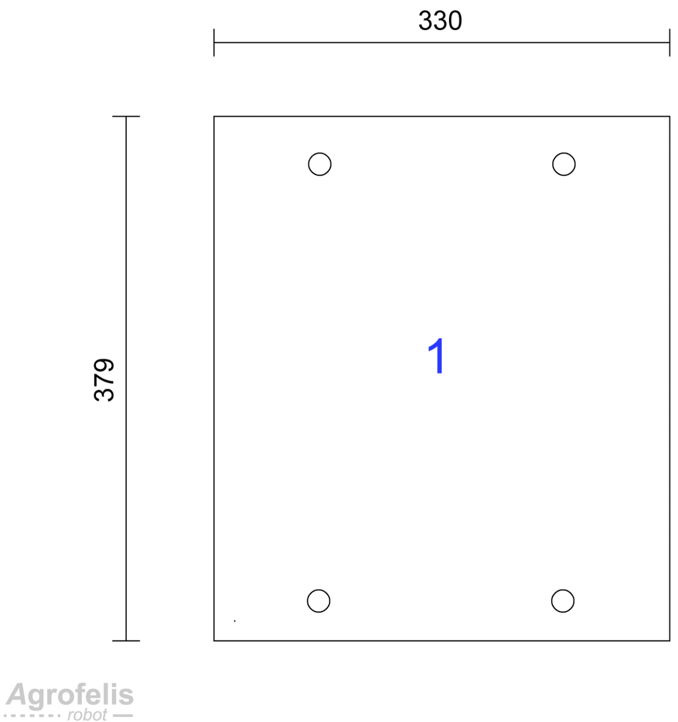


Figure 7: part 1

Figure 8: part 1 actual

Figure 9: part 1 actual-painted

Stainless Steel Horizontal Gear Disk

The following figure illustrates the schematics of the horizontal gear disk.

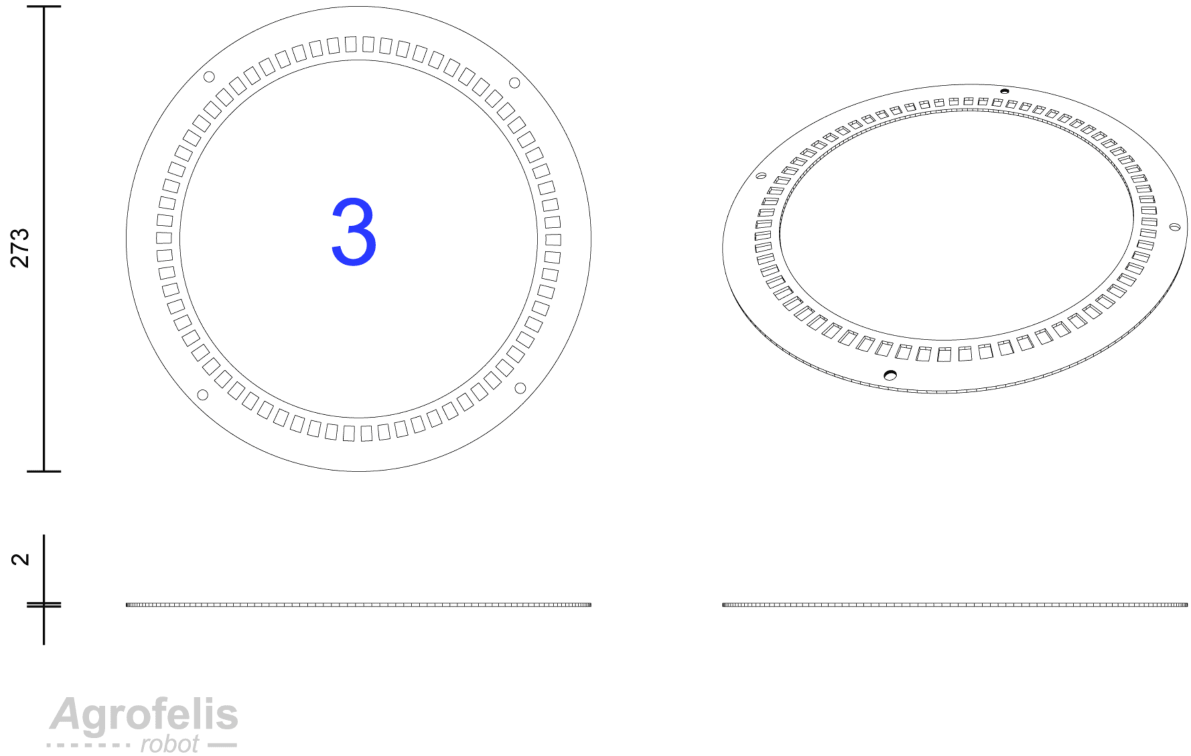


Figure 10: part 3

The horizontal gear disk was fabricated using a 2 mm stainless steel sheet, which was laser-cut by an external service, because it was too detailed for our DIY plasma cutter.

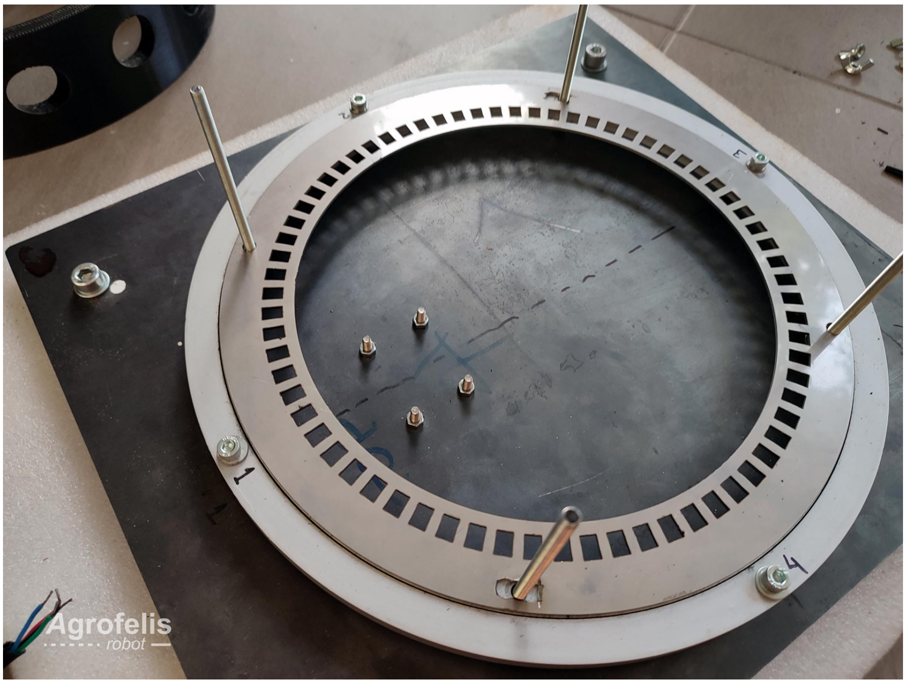


Figure 11: part 1 2 3

The design source code file that was sent to the service is available below.

- Horizontal disk gear and vertical gears file

A preview of the design source file containing the horizontal gear disk and four gears for use with three of them stacked together, is provided below.

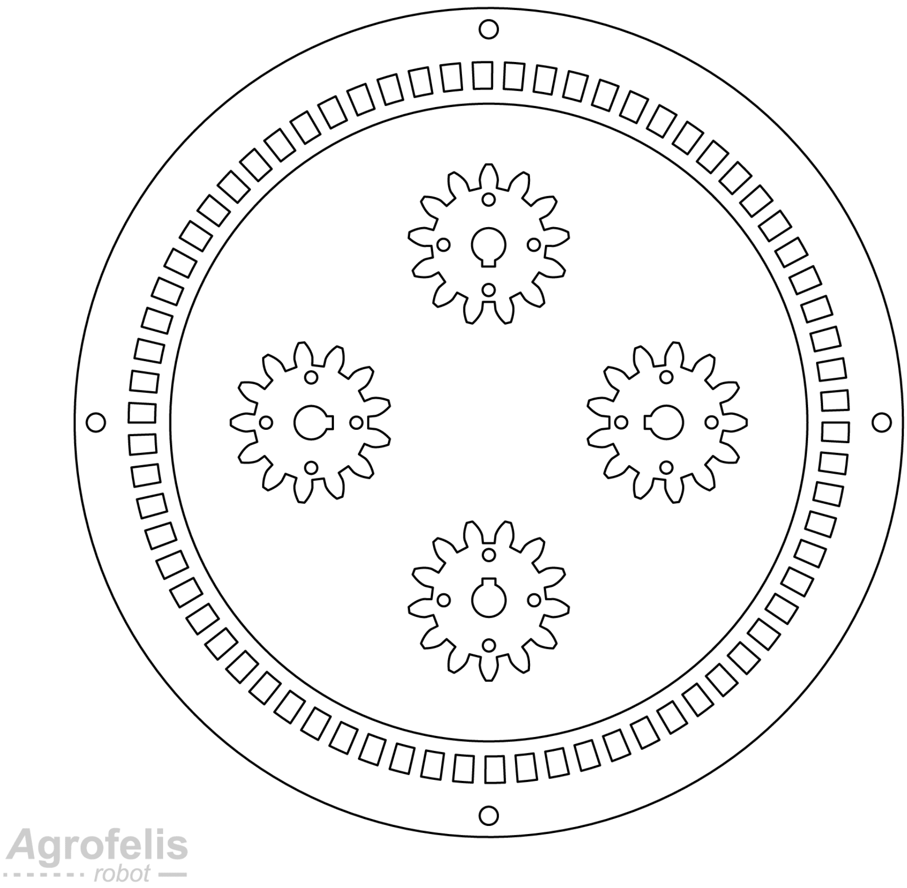


Figure 12: Laser cut drawing

Gear

The gear is comprised of three layers that are stacked and screwed together before being ground.

Figure 13: gear view

In the images below, the rounded edges created using a Dremel tool can be seen.

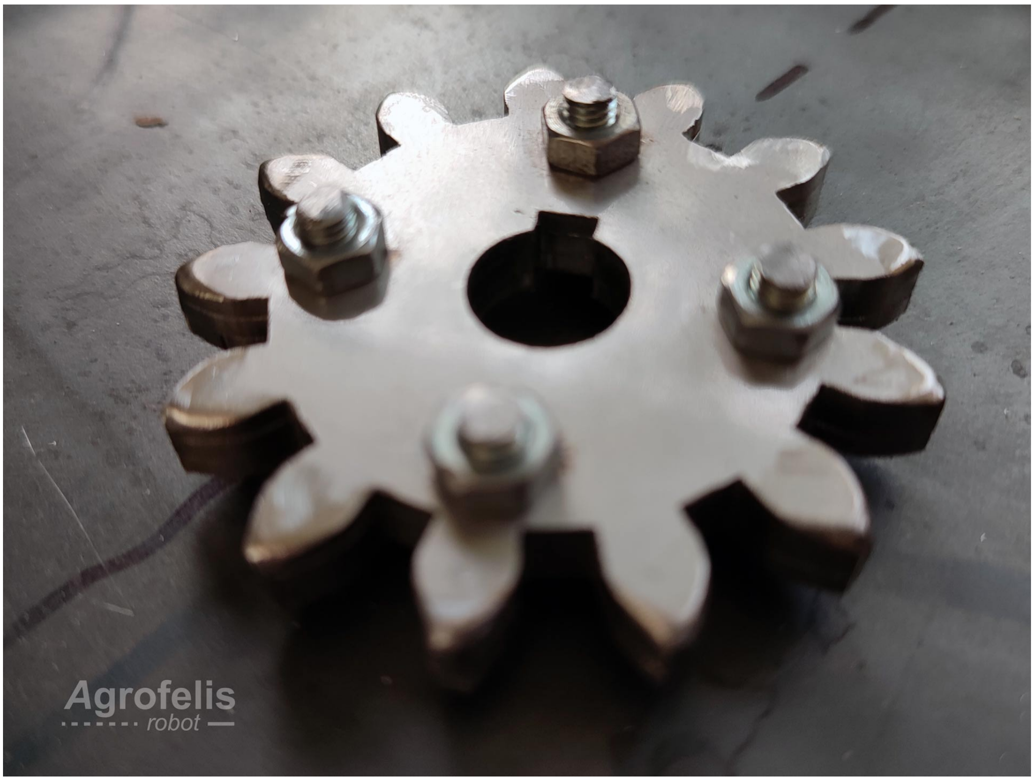


Figure 14: gear

Figure 15: gear-edge

Servo Motor

The servo motor on its mount, with its attached gear producing 0.3NM of torque, is shown below.

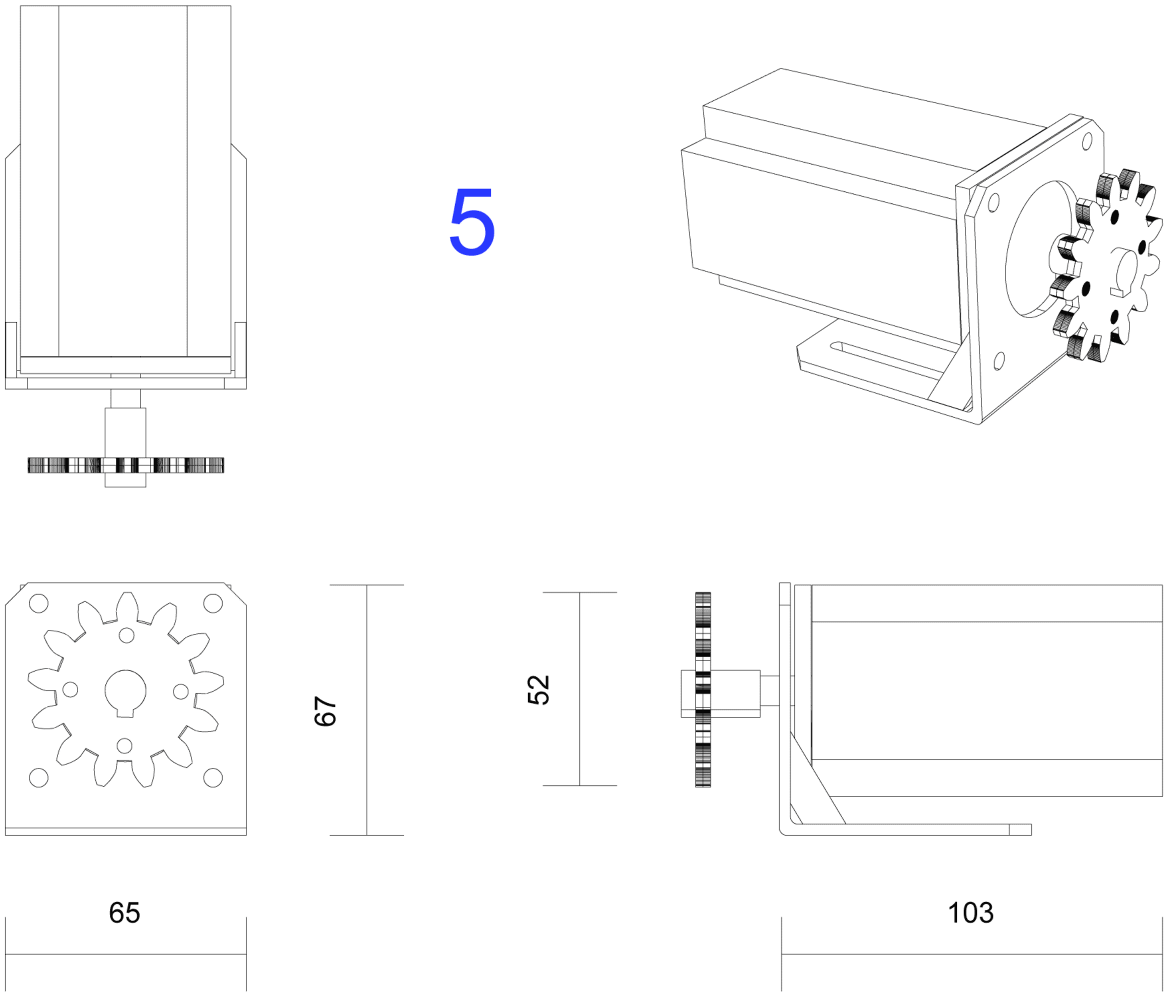


Figure 16: part 5

The complete rotating mechanism, including the horizontal gear disk, motor and gear, and four long screws, is displayed below.

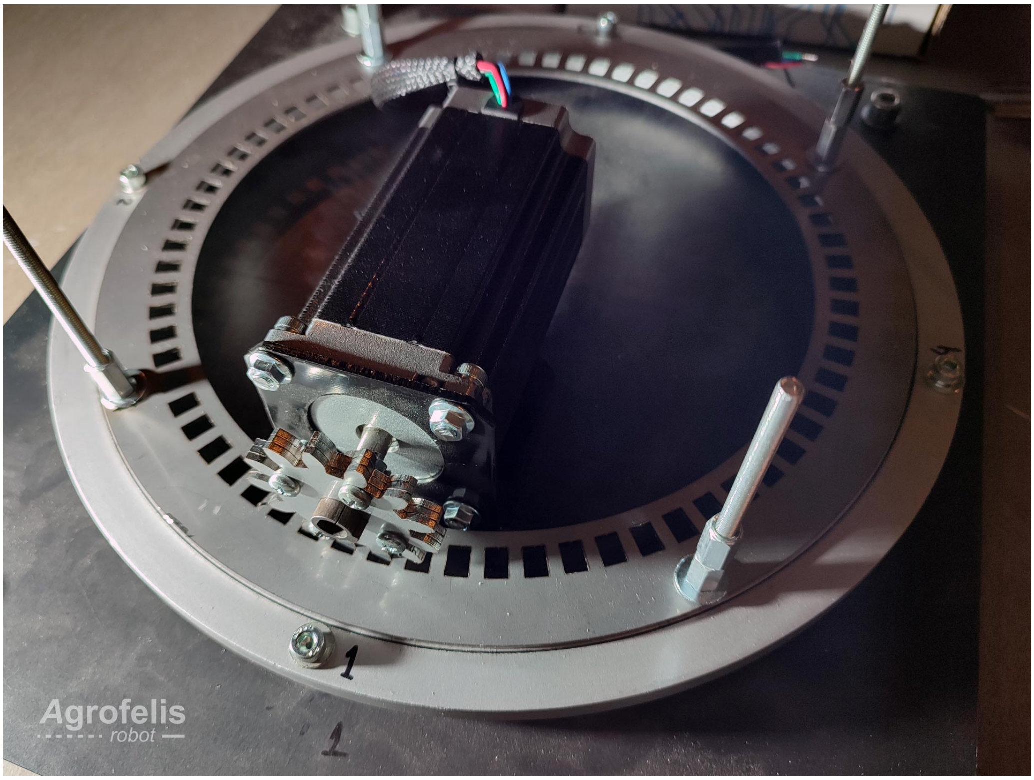


Figure 17: part 5 actual

Supporting Plastic Arcs

The plastic arcs incorporate holes that precisely fit the four long screws. These arcs provide support for the over-structure, whereas the screws primarily support the horizontal forces generated by the rotation. The entire assembly is quite sturdy.

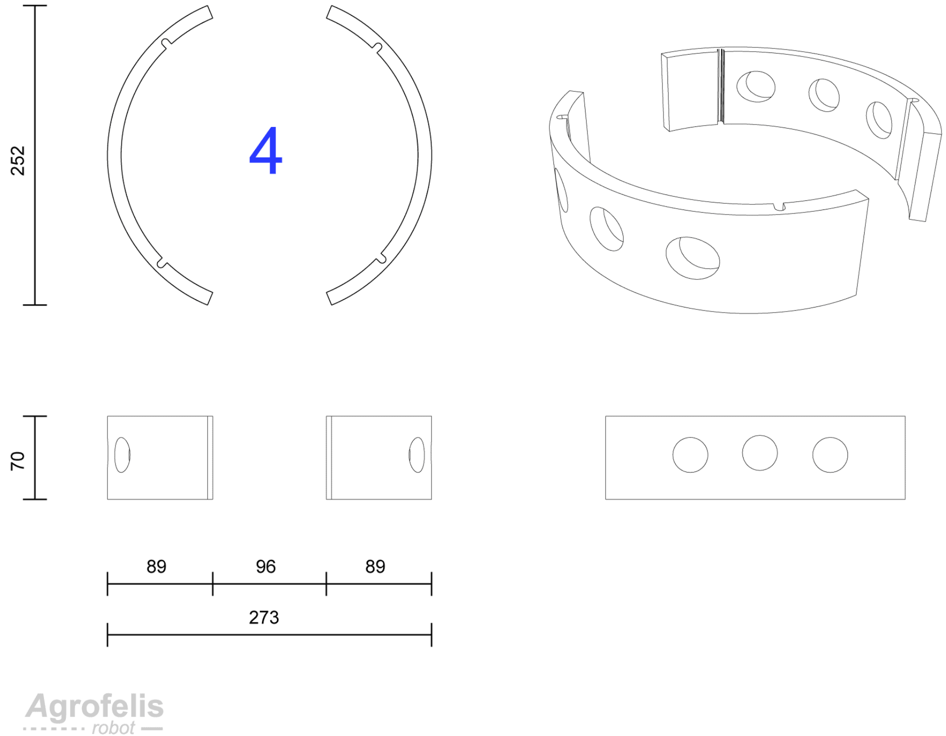


Figure 18: part 4

The assembly, including the plastic arcs, is depicted below.

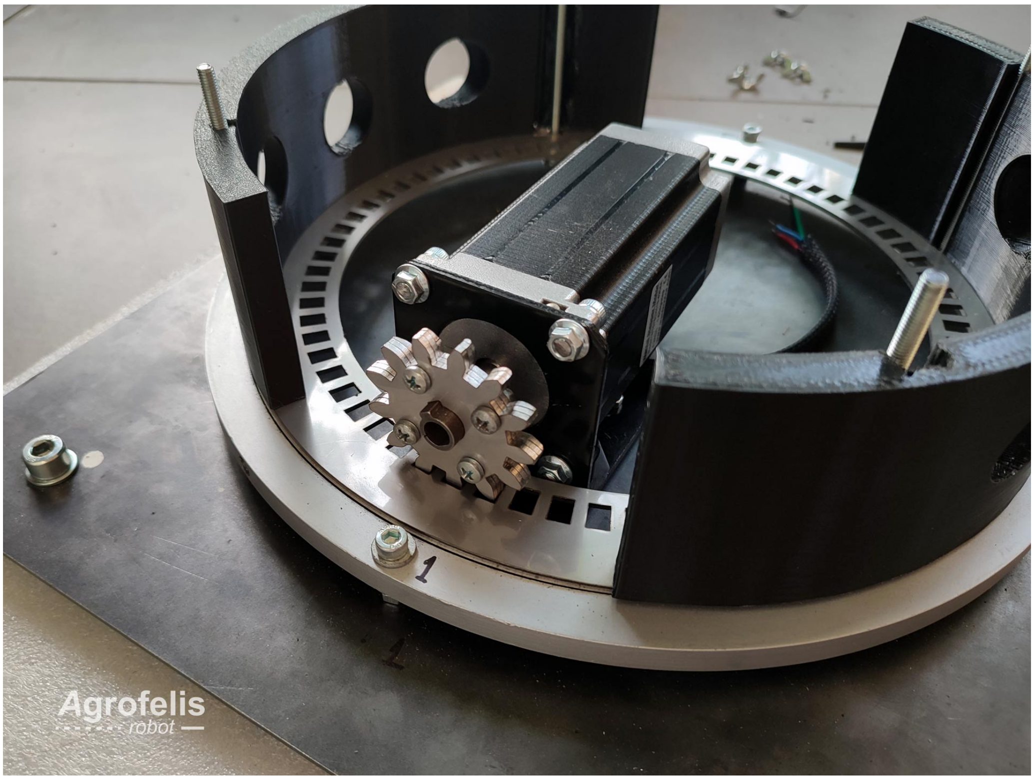


Figure 19: assembled

The source code design plans for implementing the side walls are persisted in the following path.

- Supporting side walls

Mid Base

A schematic with dimensions and photos of a plasma-cut and welded fabricated mid base is shown below.

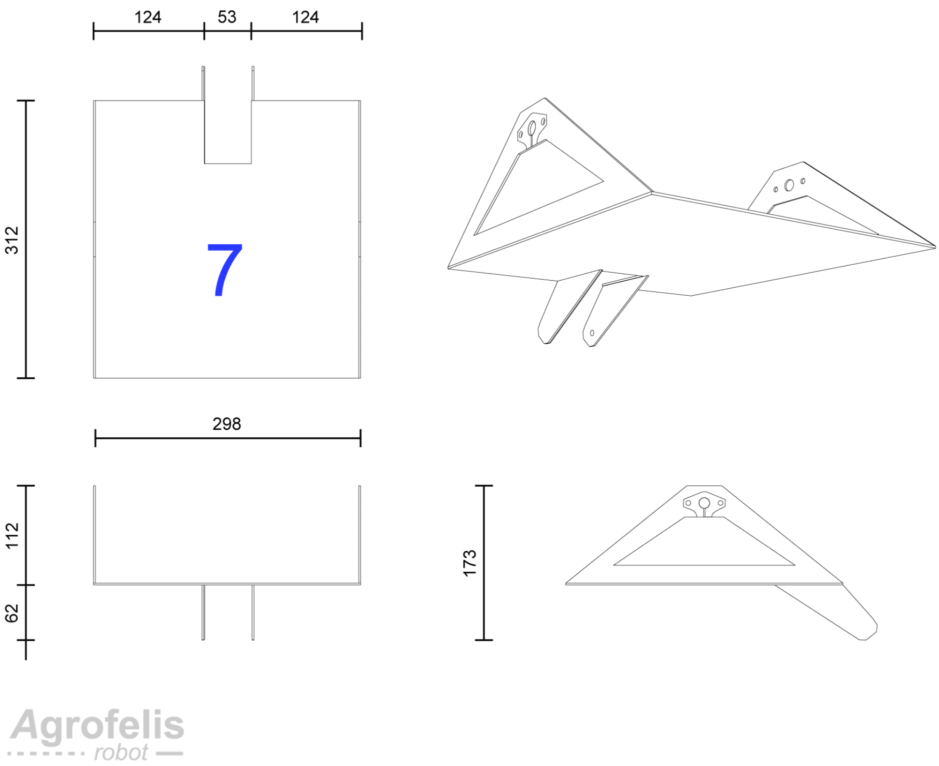


Figure 20: part 7

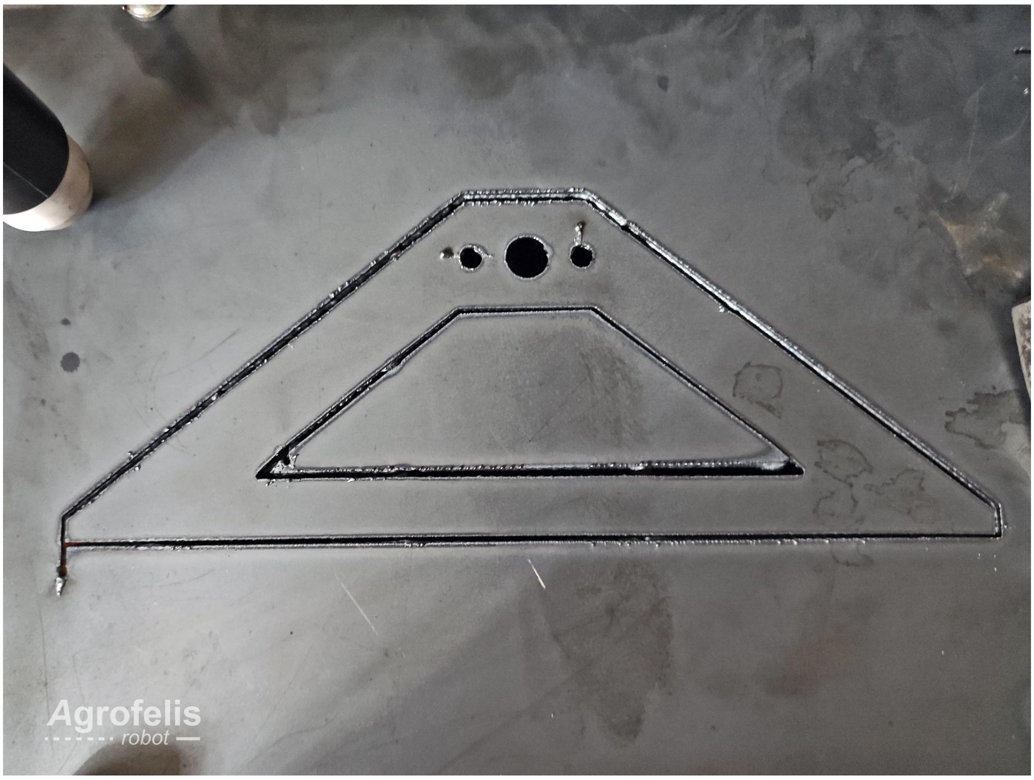


Figure 21: part 7-plasma-cut

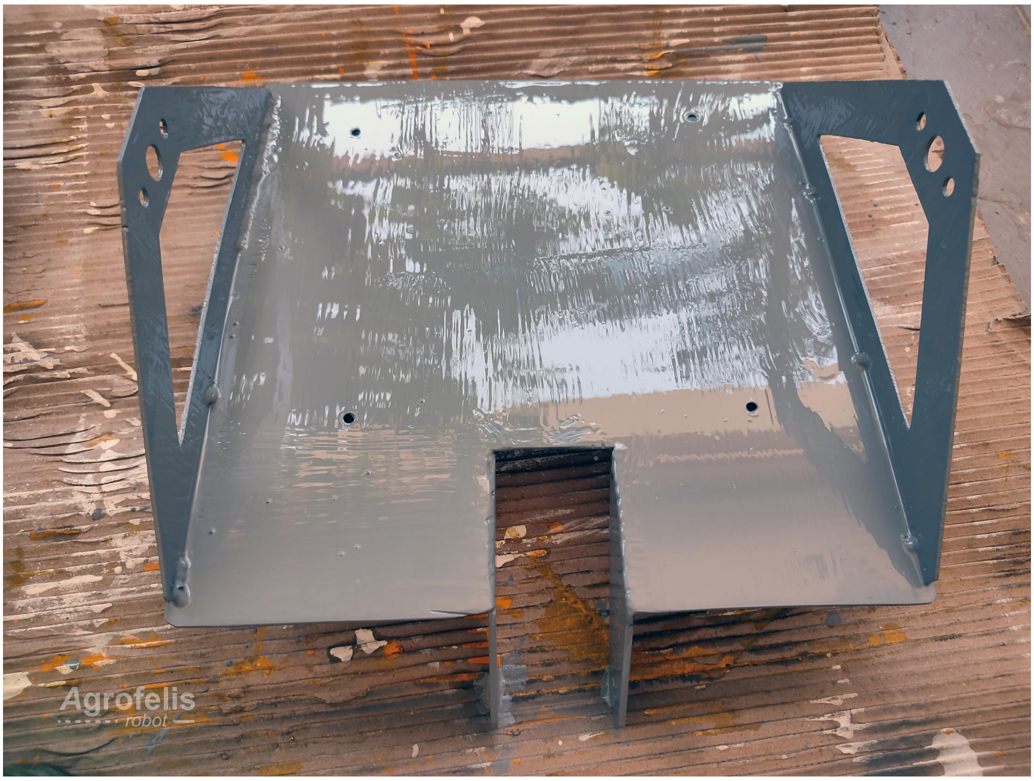


Figure 22: part 7-actual

Top Base

Details of the metal sheet used for the top base are shown below.

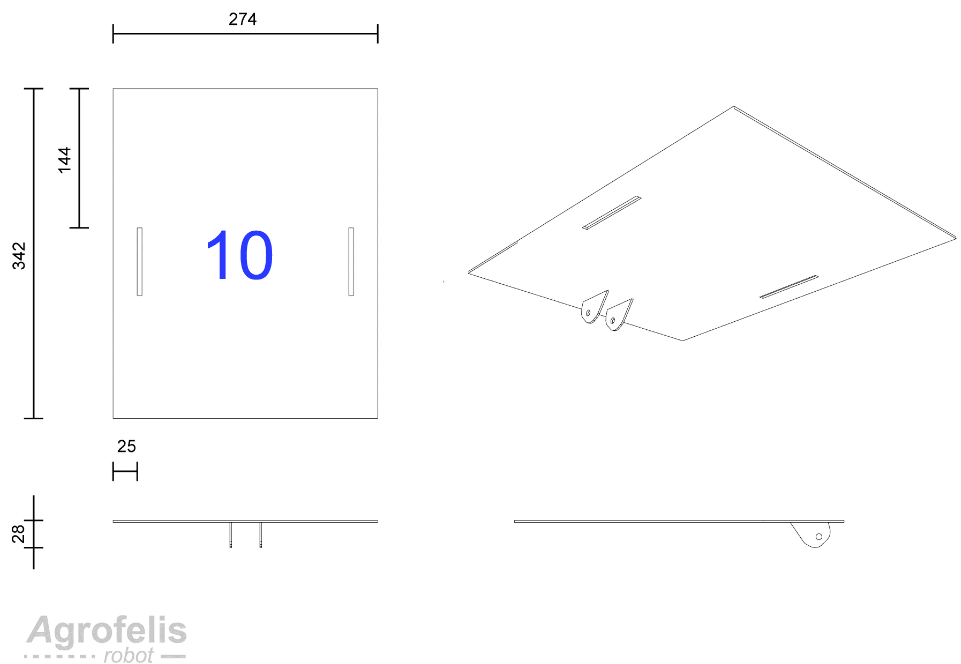


Figure 23: part 10

Figure 24: part 10-actual

End Module

The complete assembly of the Rotating Implement Mount (RIM), before being painted, can be seen in the following photographs.

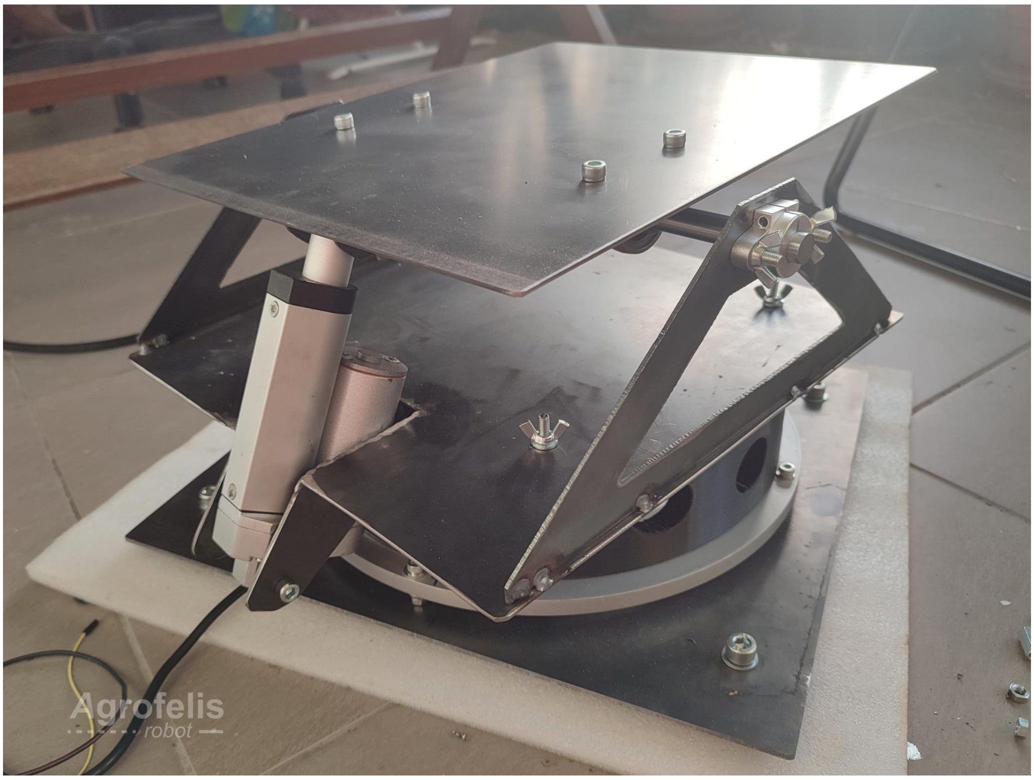


Figure 25: fabricated a

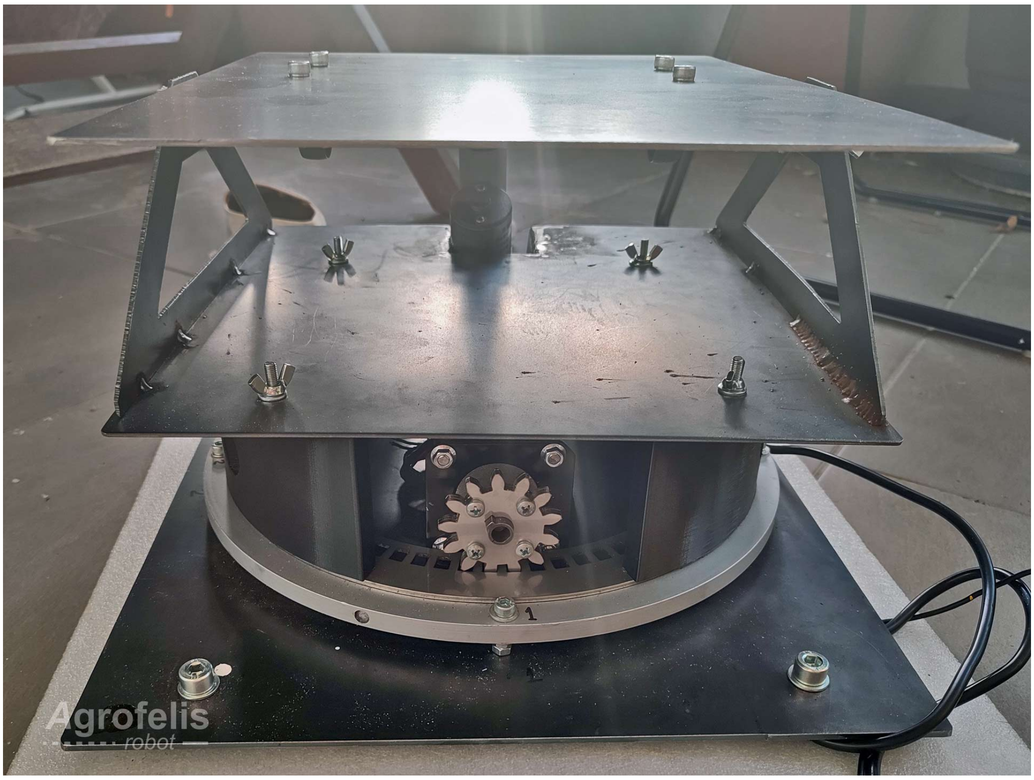


Figure 26: fabricated b

Figure 27: fabricated c

Implement Mount Components and Indicative Suppliers

The following table lists the individual components employed for manufacturing the Agrofelis two degrees of freedom rotating implement mount. The index table includes moreover the product URLs, the indicative suppliers, as well as unit prices and total cost estimates.

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#1	Black iron metal sheet 1000x2000x3mm	3mm metal sheet	QOOP Metal-works	0.2	73.85	14.77	-
#2	Black iron metal sheet 1000x2000x2mm	2mm metal sheet	QOOP Metal-works	0.3	49.23	14.76	-
#3	100 pack Allen screws DIN 912 8.8 M 8 x 25	Screws M8X25	Sinter Hellas	0	18.62	0	4 scews reused from frame material
#4	300mm Aluminium Rotating Bearing Turntable	Turntable	AliExpress	1	29.53	29.53	-
#5	Linear Actuator 50 mm 24V 200N 45 mm/s	Linear actuator	AliExpress	1	21.93	21.93	-
#6	H-Bridge Brushed DC Motor Driver	Motor driver	Cableworks	2	6.00	12.00	-
#7	NEMA23 single shaft 8mm, 4.2A	NEMA23	AliExpress	1	18.44	18.44	-
#8	Closed loop Nema 23 driver	closed loop stepper driver	AliExpress	1	21.82	21.82	-
#9	Nema 23 L bracket	Stepper bracket	ISAC Advanced robotics	1	6	6	-
#10	Linear motion shaft OD 12mm 500mm length	Linear shaft	ISAC Advanced robotics	1	8.3	8.3	-
#11	Linear shaft support bracket SHF 12mm	Linear shaft bracket	ISAC Advanced robotics	2	4.84	9.67	-
#12	Omega shaft bracket 12mm	Omega shaft	ISAC Advanced robotics	2	5.58	11.16	-
#13	750ml Vitex Metal Primer	Primer	Stereotiki	0	6.50	0.00	Reused from frame material
#14	Orange oil paint 0.75kg	Metal paint	Bousounis	1	9.70	9.70	-
#15	Brushes	Brush	Nova Ceramica	3	1.00	3.00	-
#16	White spirit	White spirit	Rigatos Shop	1	1.50	1.50	-
#17	Paper sheet	Paint paper	Xromagora	0	0.80	0.00	Reused from frame material

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#18	Laser cut gears out of stainless steel sheet 2mm as of design	-	QOOP Metal-works	1	85	85	See dwg design file
#19	3D printed side walls as of G-code	3D printing services	3DHub	1	55	55	See G-code design file
Total						**322.58**	

The total cost for manufacturing the Agrofelis two degrees of freedom rotating implement mount, excluding expenses for shipping, cutting, welding, and painting, amounts to approximately **322.58** euros.

Summary

The design rationale, component specifications, and essential dimensions for replicating the Rotating Implement Mount (RIM) of the Agrofelis robot has been documented in a progressive manner. To conclude, the photograph below showcases the vehicle equipped with the RIM, featuring a thermal fogger.

Figure 28: Agrofelis with the implement mount in a vineyard

End of document

Agrofelis Remote Controller Design and Fabrication

Documentation

Agrofelis

Document created on 2023-10-09 05:34:33

Abstract

The document presents the details of fabricating a baseline remote controller for actuating the wheels, steering, brakes and power functions of the Agrofelis robot. Emphasizing ergonomics, cost-effectiveness and the use of readily available components, a simple extendable design is presented, rapidly prototyping the minimum number of sensors and components needed for booting and controlling the mobility functions of the vehicle. The module is de-compiled using annotated design plans with crucial metrics and is re-compiled using photos captured during the fabrication process. The software source code running on the micro-controller is also presented, following approaches similar to those implemented in other Agrofelis modules. The document concludes with a list of components used and provides information on indicative suppliers, aiding in the replication of the module.

Contents

Introduction

The objective of this module is to implement a minimum viable remote controller for the Agrofelis robot. Serving its purpose in conducting the first round of on-field tests, this module acts as a baseline remote controller that can be expanded with additional modules, such as a TFT monitor, supplementary sensors and/or range extenders. The following photograph depicts the remote controller and the Agrofelis robot in operation within a vineyard.

Figure 1: Remote control and vehicle

In the following sections, the Agrofelis robot remote controller prototype is documented.

Agrofelis Remote Controller

While the Agrofelis unificator software, which integrates all Agrofelis module data streams with its corresponding web application, allows the system to be controlled through regular mobile phones and computers, there is a need for a dedicated physical interface that can be operated with one's hands, thus offering a more natural and robust interface. In addition, a dedicated physical controller bypasses issues associated with mobile phones, which are prone to interruptions from incoming calls, the necessity for clean and bare hands, distraction from the vehicle due to the necessity of looking at the RC module instead of the vehicle and usability issues influenced by ambient luminosity levels of the environment.

The designed and implemented remote controller for Agrofelis is constructed as a reversed drawer-like structure, roughly the size of an average person's chest span, thus offering a more comfortable user experience. Furthermore, the holding sides of the structure fit conveniently within the palm of the user, providing a firm grip of the module. The controller's input sensors are strategically located within thumb's reach, making it easy to access and engage with the input controls. The controller incorporates several key components, including an ESP32, a battery, a 5V step-down converter, a joystick with an embedded switch, two potentiometers and two switches, attached to the sides of the wooden structure.

Although controllers found in game engines are frequently used in such projects, this choice eventually limits the flexibility one can have. Furthermore, prototyping from the ground up builds know-how, which consequently allows the ability to extend the baseline modules based on the acquired experience. The implementation leverages established patterns and practices employed in the *Agrofelis Motors Hub Driver* and *Front Sensors Lidar* modules, further testing the decisions made, which leads to more robust software. The primary distinction between other Agrofelis modules and the basic remote controller is that the latter is simply composed of input sensors.

The controller can detect momentary button presses, prolonged presses and combinations of presses. Additionally, it quantizes the sensor signal ranges to suppress noise or accidental movements. The software actively monitors changes in the joystick's internal potentiometers, mapping forward and backward movements with its y-axis input sensor and steering with its x-axis.

The controller uses an indirect way to control the speed by varying the duration of sensor activation or inactivity. The controller fades-in the y-axis input values slower when actuated (acceleration) and fades-out of them faster when un-engaged (deceleration). The first potentiometer located on the left side limits the speed signal sent to the robot via the joystick, while the second potentiometer controls the maximum rotation degree sent to the disk brake servos, controlling how hard or soft they are actuated. The first switch powers the Agrofelis robot mobility system on or off when pressed for an extended period of time. The second switch actuates the brakes based on the signal from the second potentiometer. When the joystick's button is pressed for a prolonged time, it switches on or off the maximum or regular steering radius of the vehicle.

The software implements smooth acceleration and rapid deceleration controls for the vehicle, ensuring safe maneuverability of the module. The speed of the vehicle can be set to four speed states, ranging from zero to the maximum programmed speed. Consequently, whether on a slope or flat ground, the brakes can be adjusted to consume less energy when actuated. The remote controller was programmed and fine-tuned in the field in order to optimize its responsiveness, ensuring that the vehicle's movements were smooth, safe and forgiving by allowing users sufficient time to observe the outcomes of their movements.

The following diagram depicts the remote controller module, with distances encoded from the component to the outer rim of the controller's body.

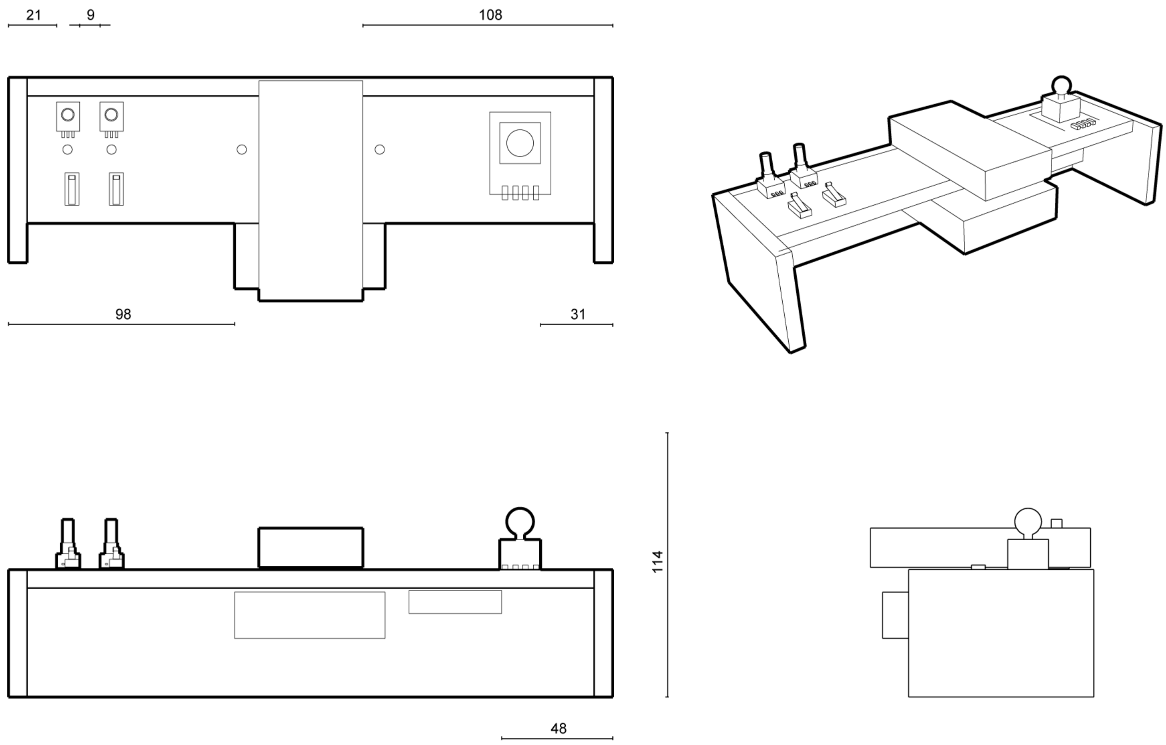


Figure 2: Module schematics

The module's components are enumerated by the consequent exploded view schematic.

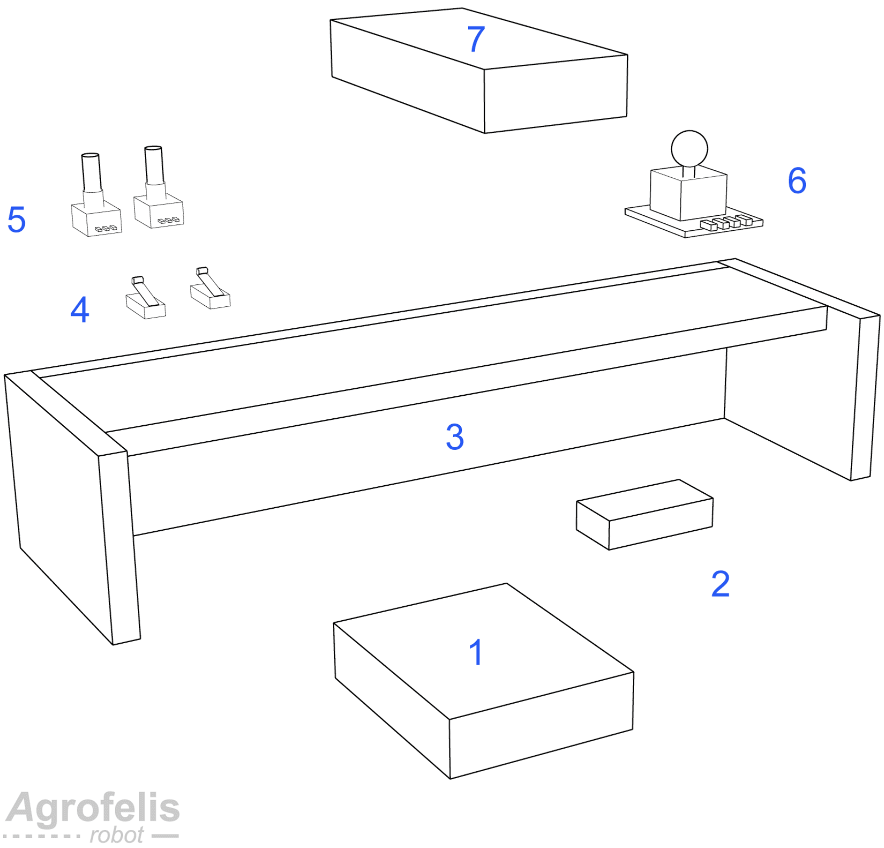


Figure 3: Module exploded view

The list below enumerates the components comprising the remote controller:

1. ESP32 38 pin on an ESP32 terminal adapter
2. 5V step-down converter
3. Wooden structure
4. Two limit switches
5. Two 10k metallic potentiometers
6. Cartesian joystick with a press-down switch
7. Battery

Structure

To prototype the body of the remote controller, the module utilised pieces of wood due to their light weight and ability to be easily drilled and machined. The structure is composed of four wooden pieces glued together to form a sturdy structure, to which the rest of the components are attached. Although the current appearance and finishing of the body are not the desired end appearance and feel of the remote controller, this rapid prototyping phase confirmed the module's approximate dimensions, the arrangement of its components, connectivity and established a functional remote controller.

The following diagram depicts the dimensions of the wooden pieces used to assemble the module's structure. Notably, it showcases two holes on the top-left side of the structure, designed for routing the cables of the potentiometers and three smaller holes matching with the pins of the limit switches layout. Two more holes can be seen in the center of the upper side of the structure for securing the battery of the remote controller, using either a strap or tape.

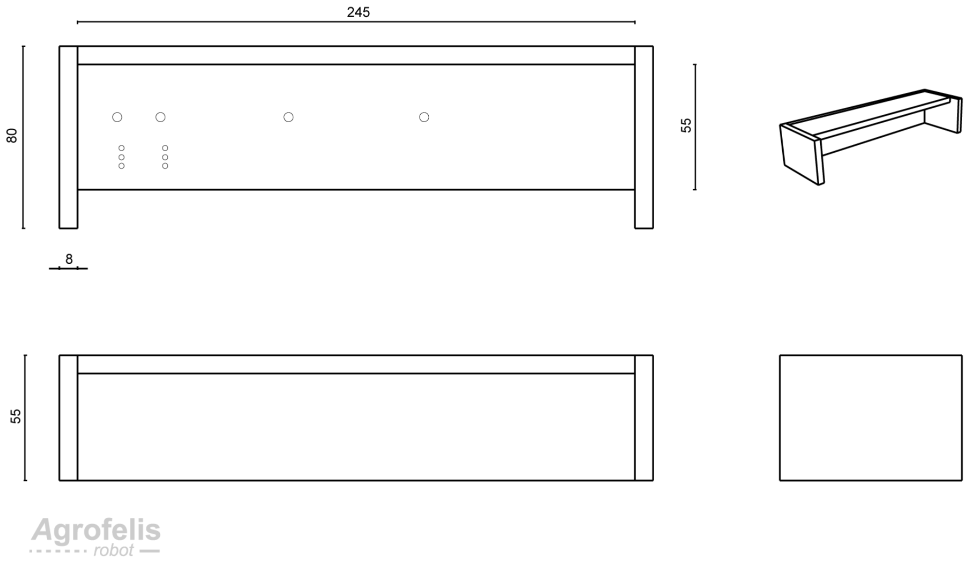


Figure 4: Structure schematics

The following photo illustrates the underside of the fabricated structure, which accommodates the ESP32 terminal adapter, attached using two screws.

Figure 5: Structure actual

The subsequent photo depicts the top side of the structure facilitating the joystick, the battery positioned in the top middle side, above the ESP32 terminal adapter which is located on the underside of the module's body.

Figure 6: Structure battery and joystick

The following photo provides a side view of the controller, captured during the same fabrication stage shown in the previous figure.

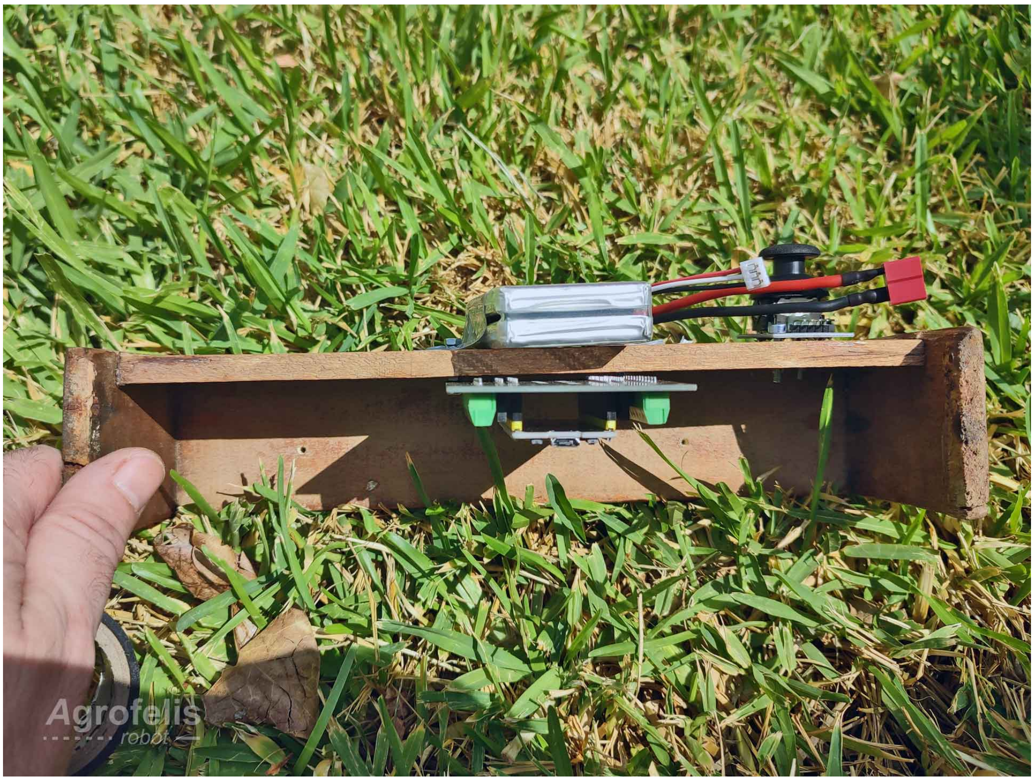


Figure 7: Module side

The following photograph focuses on the left side of the remote controller, where the two limit switches and two potentiometers have been securely attached using hot glue. The cables of the input sensors pass through the structure towards the electronics, using related holes following the layout of the components. The four input sensors are connected to the ESP32 GPIO ports using a combination of four-pin and two-pin ribbon cables, for linking their signals and supply them with power.

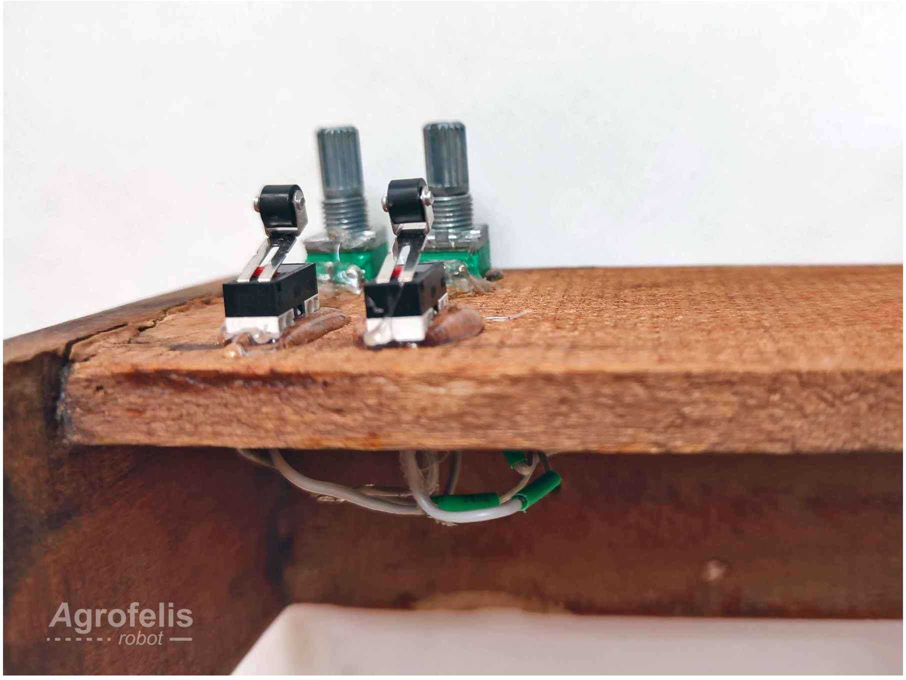


Figure 8: Switches and potentiometers

The fabricated remote controller is shown via the following photograph.

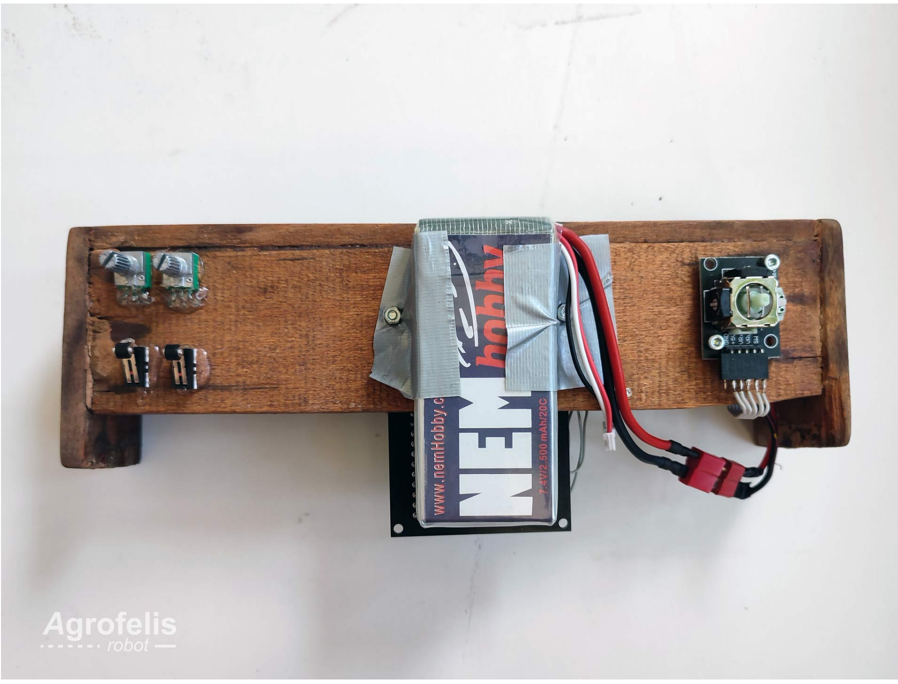


Figure 9: Top side view of module

The side view of the fabricated module, is attached next.

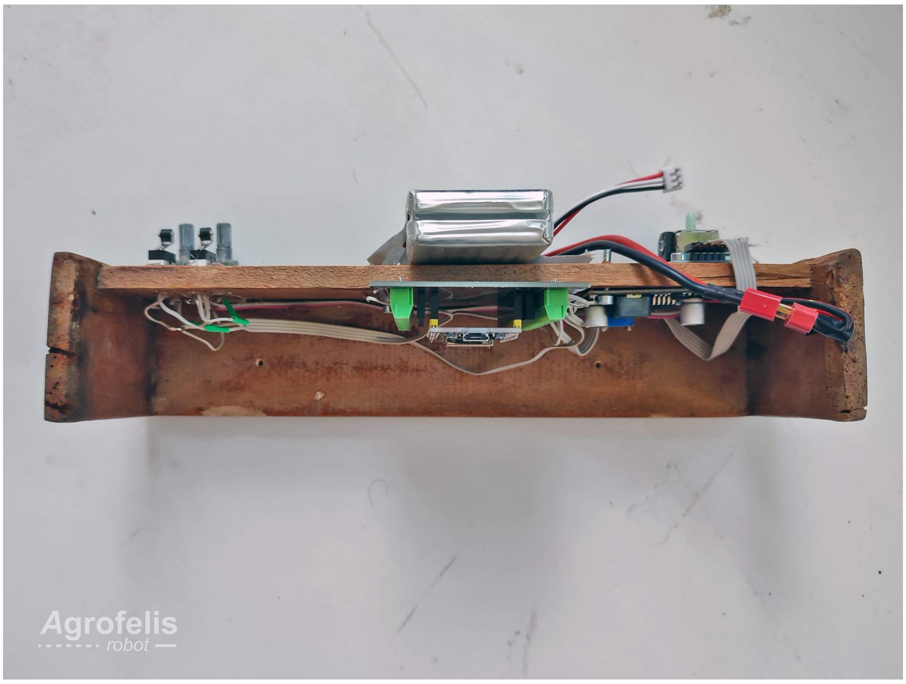


Figure 10: Side view of module

Electronics

The following photo snapshots the underside of the module, revealing its electronic components and their interconnections.

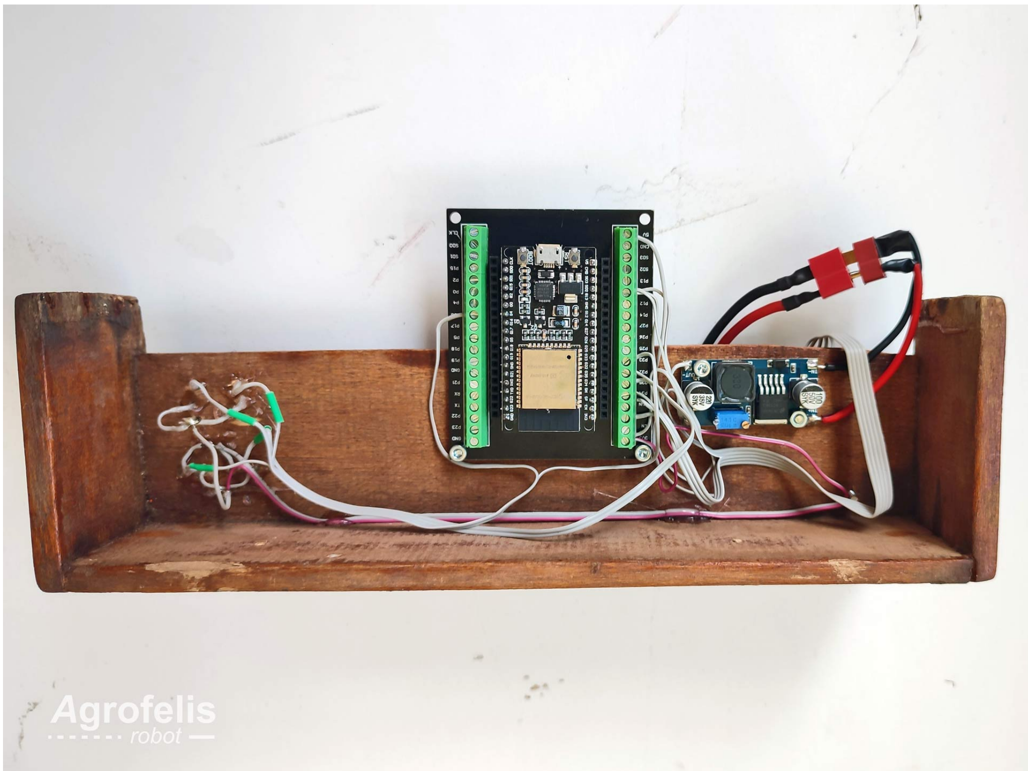


Figure 11: Underside view of electronics

The consequent photograph focuses on the left underside of the controller, where the limit switches and the potentiometer are linked with the ESP32. All sensors input pins are connected with the 3.3V output of the controller. Their output pins are connected to the digital or analogue ESP32 GPIO ports and the potentiometers are additionally linked with the ground.

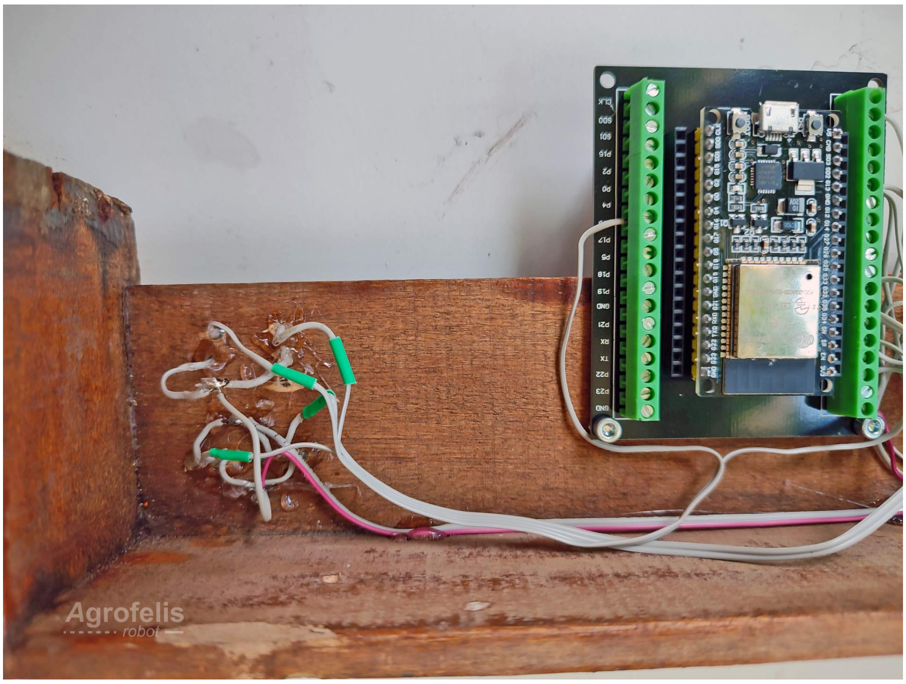


Figure 12: Under left side view of electronics

The following image depicts the right underside of the structure, where the 5V step-down converter and the right side of the ESP32 terminal pin connections are visible.

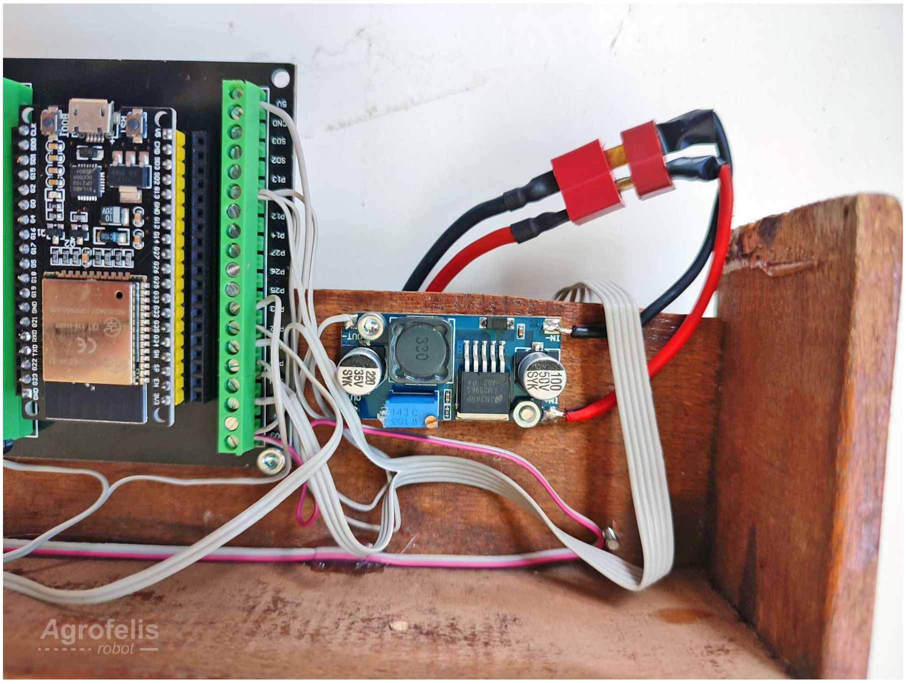


Figure 13: Under right side view of electronics

The joystick's X and Y axis sensors are connected to the 34th and 39th GPIO ports, respectively, with its tactile switch interfacing with port 36. The potentiometers on the left side are connected to ports 35 and 32. Finally, the two limit switches are linked to ports 16 and 33.

Software

This *Agrofelis base remote controller software* adheres to a common baseline pattern that has been established in nearly all Agrofelis modules. This baseline pattern introduces a "context" class, which is passed to practically all classes as a common ground, enabling instances to exchange information when necessary. The second baseline pattern established refers to the frequency of execution, providing the facilities to trigger specific functionalities at desired intervals. This design consideration accommodates for components such as an MPU or a magnetometer sensors, which require much more frequent updates compared to components such as potentiometer sensors. As a bootstrap template, the software provides six different execution frequencies, ranging from 50 milliseconds to 5-second intervals. Using this approach, delays blocking the execution are avoided and the different calls can be organized based on their responsiveness requirements.

The software encodes easy-to-follow and straightforward implementations, such as current sensors or motor(s), resulting in a one-to-one mapping between the physical element and its respective software counterpart. In this software prototype, where the module only comprised input sensors, a *Sensors module* was defined, which implemented all sensor reading and processing in a single class. The software leverages a web socket interface to communicate with the Unificator software over Wi-Fi.

The following table indexes and summarizes the classes implemented in the Agrofelis remote controller software.

Class	Description
esp32RemoteController.ino	Boots the application, initialises the top-level classes and encodes the triggering frequencies of the functional elements.
Context	Provides a common ground for sharing information and encodes the triggering frequencies, helpful functions and a unique identifier of the model.
Invoker	Tracks the execution frequencies so these are called at the right time.
Sensors	The class defines the pin ports of all input sensors. The software reads all input sensors based on their type in one step and in a second step evaluates their combinatorial state and amount of time being actuated, triggering accordingly a respective command action to be sent to the Agrofelis robot.

Remote Controller Components

The following table lists the individual components employed for prototyping the Agrofelis remote controller. The index table includes moreover the product URLs, the indicative suppliers, as well as unit prices and total cost estimates.

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#1	ESP32 38-pin	ESP32	AliExpress	1	3.67	3.67	-
#2	ESP32 38-pin terminal adapter	ESP32	AliExpress	1	2.69	2.69	-
#3	100 X 80 X 8 mm ply-wood	Plywood	Skroutz	1	16.02	16.02	-
#4	Gravity: Joystick Module V2 (DFR0061)	Joystick	Hellas Digital	1	6.20	6.20	-
#5	10K Ohm Linear Potentiometer B10K 15 mm	Potentiometer	Hellas Digital	2	0.50	1	-
#6	5V step down converter	Step-down converter	GRobotronics	1	2.90	2.90	-
#7	Micro limit switch	Limit switch	GRobotronics	2	0.20	0.40	-
#8	5 wire, 4-wire and 2-wire ribbon cable	Ribbon cable 28AWG	GRobotronics	1	1	1	-
#9	NEM Li-PO 7.4v/ 1500mAh/ 20C	Battery	NEM hobby	1	15.00	15.00	-

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#10	Connector T-Plug Gold Plated -Male	T-plug	NEM hobby	1	0.62	0.62	-
#11	Black and red wire	Black-red wire	GRobotronics	0	8.00	0.00	Shared Component
Total						**65.52**	-

The total cost for manufacturing the Agrofelis remote controller prototype, excluding shipping and labor costs, amounts to approximately **65** euros.

Summary

The rationale of the module, its sub-components and their elements were elaborated. Photos outlining details of the different phases of the manufacturing process were provided. Source code files, schematics, instructions and printouts to reconstruct the Agrofelis basic remote controller have all been documented. The document concludes with a photo of the remote controller being held by the robot's operator.

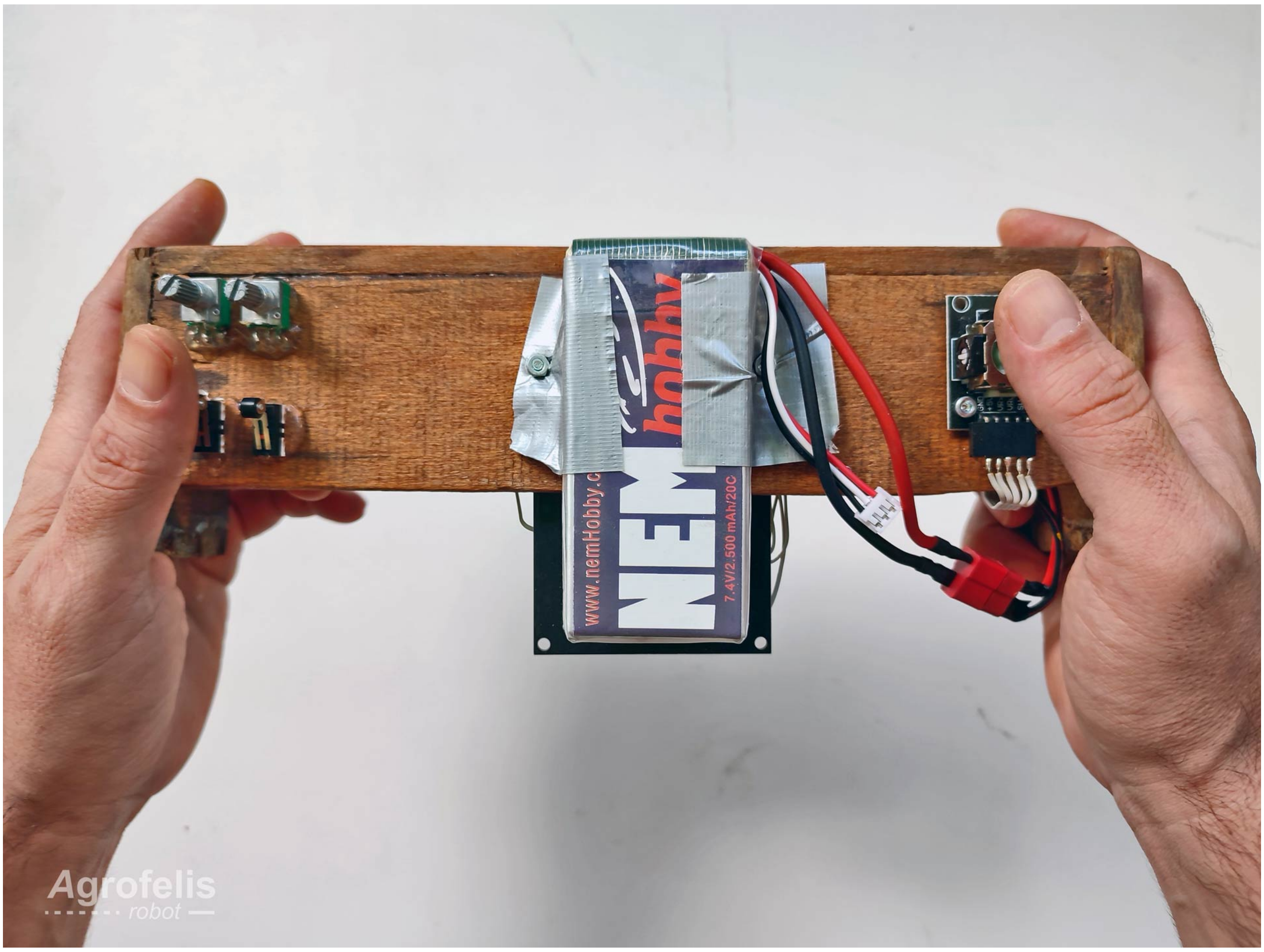


Figure 14: Remote control being held

End of document

Infrastructure Provisioning, Computing Elements and Data Fusion

Documentation

Agrofelis

Document created on 2023-10-09 05:40:56

Abstract

The document presents the provisioning of the main computing elements for the Agrofelis robot and the initiation of its services. The peripheral elements established and attached to the local Agrofelis WiFi network and its USB hub are enumerated. In addition, the GPU component and the neural network accelerator tapping to the USBv3 interface of the Jetson Nano are presented. The Agrofelis Unificator Software, which connects all Agrofelis modules, is introduced along with its source code and features. The document also provides information on lightweight 3D printed structural elements that fit in the limited space available for the USB cables and secure the components and the USB hub in their compartment. The document concludes with a list of the components used and indicative suppliers, aiding the replication of the Agrofelis computing and networking systems.

Contents

Introduction

The main computing elements of the Agrofelis robot are located in its back section on top of the steering plates. The following figure depicts their locations.

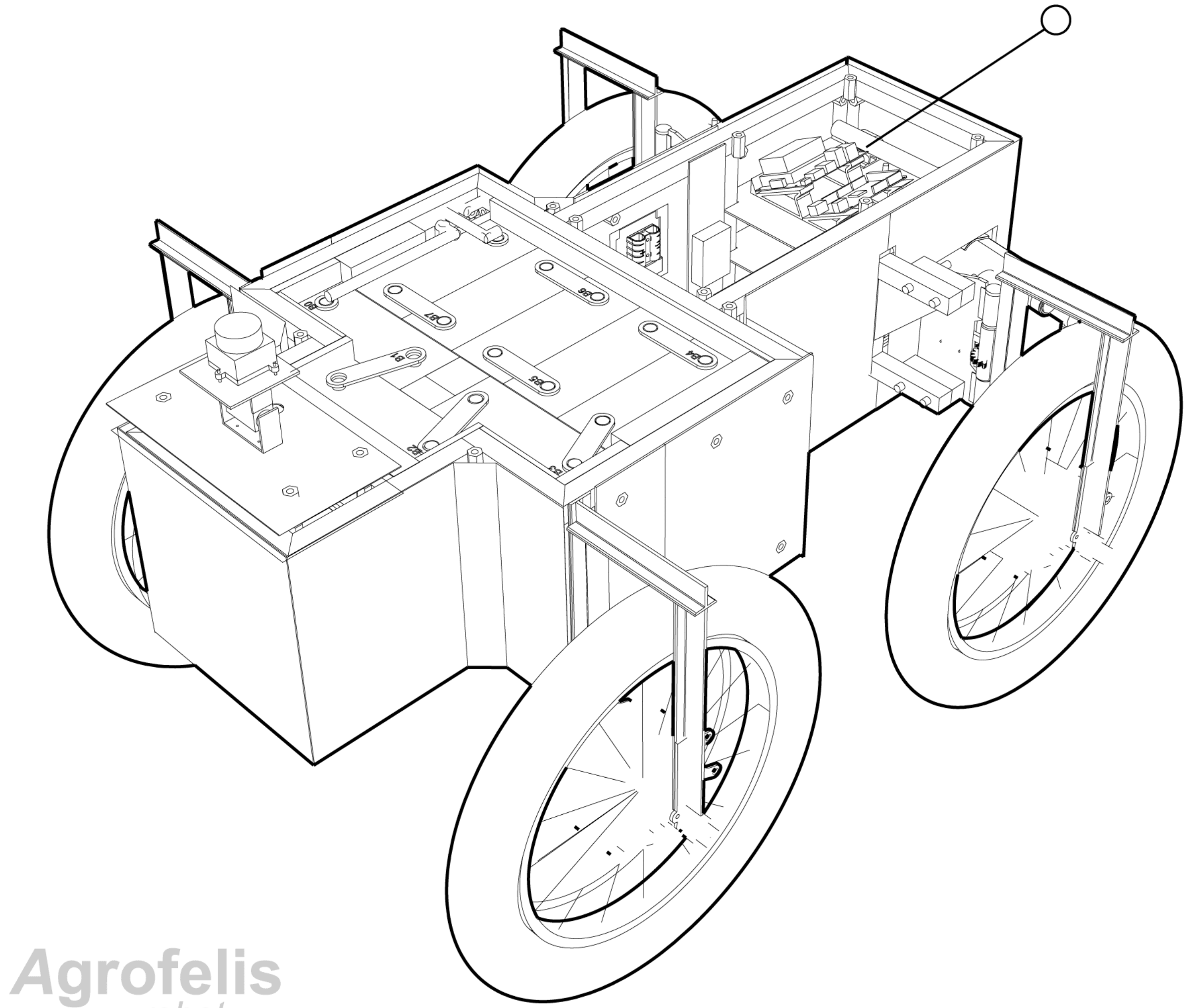


Figure 1: Overview

A relatively low-cost, fully-fledged GPU-capable computer, optimized for a small footprint and energy efficiency, aimed for AI applications, has been employed for the robot.

Figure 2: Jetson Nano

The computer is equipped with a high-speed 128 GB SD card with read and write speeds of 290 and 260 megabytes per second, addressing one of the key bottlenecks of the Jetson Nano computer.

Figure 3: high speed sd card

Furthermore, the Jetson Nano is equipped with an AI accelerator module connected to the USB3 port, expanding its capacity for parallel processing and neural network inference.

Figure 4: Coral accelerator

The Jetson Nano is machine vision ready, supporting high-speed, high-resolution camera inputs. The following photograph snapshots the camera of the Agrofelis robot, along with its 1-meter cable extension, connecting the computer to the front section of the vehicle.

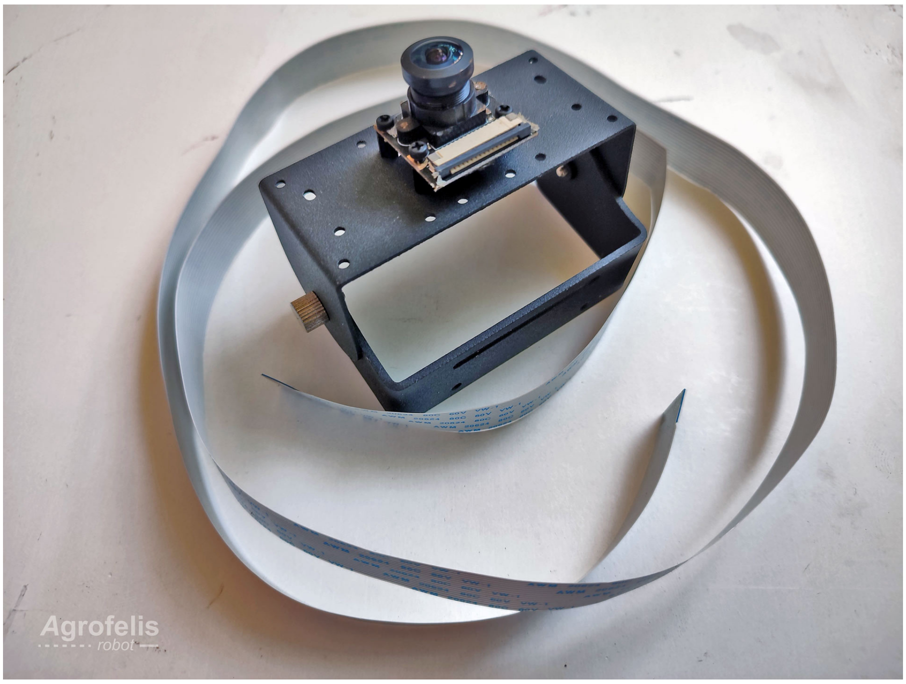


Figure 5: Camera and 1m cable

In the following sections, the details of provisioning the Jetson Nano computing module and its services, are documented.

Jetson Nano Operating System Provisioning

To initialize the computing module, one needs the same components as for a regular computer. In particular, there is a need for a keyboard, a mouse, a monitor, and a hard disk (SD card). An operating system can be written to the SD card using a turnkey Ubuntu-based image configured by NVIDIA, which has most of the needed software installed. The official getting started document can be followed to get acquainted with the embedded computer and bootstrap it.

Following NVIDIA's documentation, the 6.4 GB compressed operating system image can be downloaded from the following link.

- https://developer.nvidia.com/jetson-nano-2gb-sd-card-image

Due to the large file size, it is recommended to download it from a fast and stable internet connection. To write the image to the SD card, a Windows or a Linux computer can be utilised with the balenaEtcher as recommended by the NVIDIA documentation. Once the SD card is written it can be slotted in its placeholder and the computer can be connected with a 5V power supply.

Upon system initialization, the USB WiFi adapter or a network cable can be attached and used to connect to the internet in order to get the latest available updates, using the following commands.

```
apt-get update
apt-get get upgrade
apt-get autoremove
apt-get dist-upgrade
```

Two handy tools, one for monitoring the hardware resources of the computer and the other for multiplexing multiple command terminals, can be installed using the following command.

```
apt-get install htop screen
```

Once the Jetson Nano has been connected into the network, the monitor, keyboard and mouse can be removed and the computer can be operated using an SSH terminal. Although not essential, the computer can also be set up to stream its monitor using the open-source VNC software by issuing the following commands.

```
mkdir -p ~/.config/autostart
cp /usr/share/applications/vino-server.desktop ~/.config/autostart/.
gsettings set org.gnome.Vino prompt-enabled false
gsettings set org.gnome.Vino require-encryption false
gsettings set org.gnome.Vino authentication-methods "['vnc']"
gsettings set org.gnome.Vino vnc-password $(echo -n 'agrofelis'|base64)
```

The commands initialize a remote desktop server which can be handy when debugging for the first time the video camera, or alter the WiFi network settings or other settings provided by the graphical user interface of the operating system. The computer's monitor feed can be accessed using another computer via the freely available VNC viewer software.

Agrofelis Containerized Services

As observed, the operating system can be setup with just a handful commands, primarily because all common requirements have already been provisioned by NVIDIA in the aforementioned image. Another very useful software already pre-installed in the system is the NVIDIA Docker. Docker allows to containerize arbitrary computing environments, instantiate multiple instances of them and also revert, reuse or extend their definitions. Employing the Docker technology in the Agrofelis software stack means that its systems are easily reproducible, their definitions are transparent and their execution is somewhat isolated from the main operating system. Employing Docker, allows the operating system to remain clean of the application's dependencies and new technologies can be evaluated without the fear of "polluting" the system. The installed NVIDIA Docker variation can interface with the GPU hardware of the embedded computer which enables it to containerize AI applications.

In total, five Docker images have been developed, each layering functionality in a reusable manner, out of which two are mandatory for the robot's operation. The developed docker images are elaborated in further detail via the following table.

Image Name	Extends	Necessary	Description
agrofelis.unificator	node:16.17.0-bullseye-slim	Yes	The image extends the slim version of the main stream NodeJs image used to run the Agrofelis Unificator application. The particular image was found to have the smallest available footprint while still being able to run the intended application without further additions.
NGINX	Directly used	Yes	Although an image is not defined, a relevant folder is created next to the Agrofelis images definitions for persisting the NginX settings files that are mounted on the main stream container at the time of its instantiation. Nginx is the second most popular web server which at the same time is very lightweight and very fast because its implemented in C++. The Nginx docker instance is able to index and serve the www folder containing the web applications of the Unificator and of individual Agrofelis modules.
agrofelis.os	ubuntu:22.04	No	The docker image extends the main stream Ubuntu 22.04 operating system image, setups the local timezone related settings and installs some open source tools such as decompression, file synchronization, networking and file editing utilities. The image serves as a foundational layer used by consequent Agrofelis docker images as well as for evaluating new software on ephemeral instances.
agrofelis.os.arduino	agrofelis.os	No	The image extends the agrofelis.os foundational image and installs the arduino-cli command line tool, with it one can compile the Agrofelis steering module using an Arduino Mega and renew its firmware. The docker image definition encodes furthermore the exact 3rd party open source libraries required to compile the source code of the module. Although its not necessary to be able to compile the various micro-controllers firmware modules from the robot hardware, its convenient to share a transparent reproducible environment that anyone can effortlessly reuse to compile the software of the relevant modules. Having this docker image enables one to program the robot with just a regular computer with basic text processing capabilities. Moreover it could offer firmware updates by deploying a fraction of their binary size. The image source code can also be modified to compile the firmware of the ESP32 which is updated over the air.
agrofelis.os.R	agrofelis.os	No	The image extends the agrofelis.os foundational image and equips the environment with the R programming language focusing on statistics, machine learning and data manipulations and visualisation. The image is equipped with few powerful R packages the data.table a lighting fast data table manipulation engine and the FST package offering a very performant way of storing and compressing numerical information well balanced between the time needed to restore/write and the size needed to persist the information on disk. The combination of these packages and the power of the R language provide a very efficient framework to conduct data processing and machine learning procedures as well as rapidly prototype new applications.

File System Provisioning

The file system of the Agrofelis software is organized within the root path of the Jetson Nano operating system, in a folder named:

- /web-pub

The file system can be populated by exporting the connectivity/ folder from the github repository and positioning it within the /web-pub folder of the Jetson nano. Following the filesystem installment and to have the web applications folder in a more prominent position, the **www** folder contained within the **connectivity** folder just established, is relocated within the **/web-pub/** folder. Lastly for testing the steering source code compilation and firmware upload functionality, the source code of the steering module is exported and located at the **/web-pub/arduino/2023** folder.

Docker Images Provisioning

The Docker images definitions are contained within images folder established in the previous section. Respective folders named after the name of the aforementioned Agrofelis images contain a **Dockerfile** encoding the exact commands extending and adapting their related base image. The images folder provides one-line commands to easily provision the environments from scratch. The following example builds on the previously presented images.

```
cd /web-pub/connectivity/src/agrofelis-unificator/docker/images

./01.build.agrofelis.unificator.sh
./02.build.agrofelis.os.sh
./02.build.agrofelis.os.R.sh
./03.build.agrofelis.os.arduino.sh
```

Docker Images Instantiation

One folder above the images definitions path, named docker contains one-line commands instantiating the related containers based on their names as follows.

```
cd /web-pub/connectivity/src/agrofelis-unificator/docker
```

NginX

The following command instantiates the Nginx service and mounts the related setting files to the container:

```
./20.init.nginx.sh
```

Once the service is initiated, it will automatically start on systems boot or restart automatically if any issues arise.

Unificator

The following command will initiate the container running the Unificator Software. The instantiation command, apart from mounting the Agrofelis Unificator Node.js application source code, mounts privileged hardware resources namely the Arduino Mega steering system as well as that of the Front Sensors Lidar's USB connections. The command also exposes and links the port 8080 of the host machine with that of container's. Finally, it initiates the Unificator application using the Node.js technology and opens a WebSocket server on port 8080.

```
./01.init.agrofelis.unificator.sh
```

Supportive

To instantiate an ephemeral Ubuntu server as an evaluation environment, the following command can be issued.

```
./02.init.agrofelis.os.sh
```

Similarly, to instantiate an ephemeral Ubuntu server for conducting data manipulation experiments, the consequent command can be issued.

```
./04.init.agrofelis.os.R.sh
```

Finally, to compile and upload the firmware for the Arduino Mega steering system, the following command can be applied.

```
./03.agrofelis.arduino.compile.sh
```

Please note that when uploading firmware to the microcontroller, ensure that the USB connection is not already reserved by another application. To stop the Agrofelis Unificator Docker instance, the following command can be executed.

```
docker rm -f agrofelis.unificator1
```

All Docker instances running on the host machine can be listed using the following command.

```
docker ps
```

The consequent command can be used to monitor the hardware resources occupied by each container.

```
docker stats
```

GPU and TPU Computing Modules

The Jetson Nano, apart from having a multicore processor, is also equipped with a 128-core Maxwell GPU module capable of implementing machine learning and machine vision tasks. This GPU allows for running multiple neural networks in parallel, making it suitable for applications such as image classification, object detection, segmentation, and speech processing [1].

Another remedy equips the Agrofelis robot with additional machine learning capabilities, by employing the Coral Accelerator, which adds an Edge TPU coprocessor to the system, enabling high-speed machine learning inferencing [2]. The addition becomes highly efficient because Jetson Nano has one USB version 3 which can utilise the high speed throughput of the Coral Accelerator. The on-board Coral Edge TPU coprocessor is capable of performing 4 trillion operations (tera-operations) per second (TOPS), while using only 0.5 watts f per TOPS (2 TOPS per watt). For example, it can execute state-of-the-art mobile vision models such as MobileNet v2 at nearly 400 FPS, in a power efficient manner [3].

Being able to perform machine vision tasks at the edge, creates a robust system that operates independently of internet connectivity, enhancing its robustness and autonomy.

Agrofelis Unificator

The Agrofelis Unificator Software purpose, as its name suggests, serves the purpose of seamlessly integrating an arbitrary number of modules, regardless of their data streams, protocols, or bus types. The lightweight Agrofelis application was built on the NodeJS technology, due to its high performance and non-blocking I/O capabilities. The Unificator establishes connections with modules that utilize the USB interface, such as the Steering/Braking modules and the Front Sensors Lidar. Additionally, the application communicates with two WiFi power relay modules via the HTTP protocol. Lastly, the Unificator application establishes a connection with three modules utilizing the Websockets interface, namely the two MotorHubDrivers as well as the Remote Controller. The software moreover relays the information and routes commands to the appropriate module.

The Agrofelis Unificator server records unified data streams and rotates and archives them in compressed assets when they reach approximately 1 MB in their raw form. Notably, Lidar log data are stored in a separate file from the rest of the modules due to its significantly higher data rate compared to all the other modules combined. The application also tracks how far in time the archive folder has data for and erases older data batches to prevent occupying the entire disk space.

The application has been implemented within 200 lines of code, rendering the server easily maintainable. Using the overall recopy allows the Agrofelis modules to be operated as individual modules, but also as part of a collection. The technologies employed and the design principles, enable arbitrary hardware and software modules within the Agrofelis network to seamlessly integrate with the rest of the modules, thereby expanding the capabilities of the Agrofelis robot.

The Agrofelis Unificator Software is located in the following path.

[1] https://www.raccoons.be/resources/insights/performance-comparison-:-coral-edge-tpu-vs-jetson-nano "Performance comparison : Coral Edge TPU vs Jetson Nano"

[2] https://coral.ai/products/accelerator "Coral USB Accelerator"

[3] https://coral.ai/examples/ "Coral application examples"

- /web-pub/connectivity/src/agrofelis-unificator/server

The software depends on few JavaScript libraries used for accessing the HTTP protocol, the Serial bus and the WebSockets interface, as well as for performing asynchronous web requests. These dependencies can be downloaded using the following commands.

```
apt-get update;
apt-get install python3;
npm install http serialport websocket axios
```

Multiple agents can connect to the Agrofelis Unificator server to observe, control, or supplement its operation. For instance, the Remote Controller can connect to the server simultaneously with another user observing data via the Unificator client-based web application. The following screenshot showcases the web application view in the aforementioned scenario.

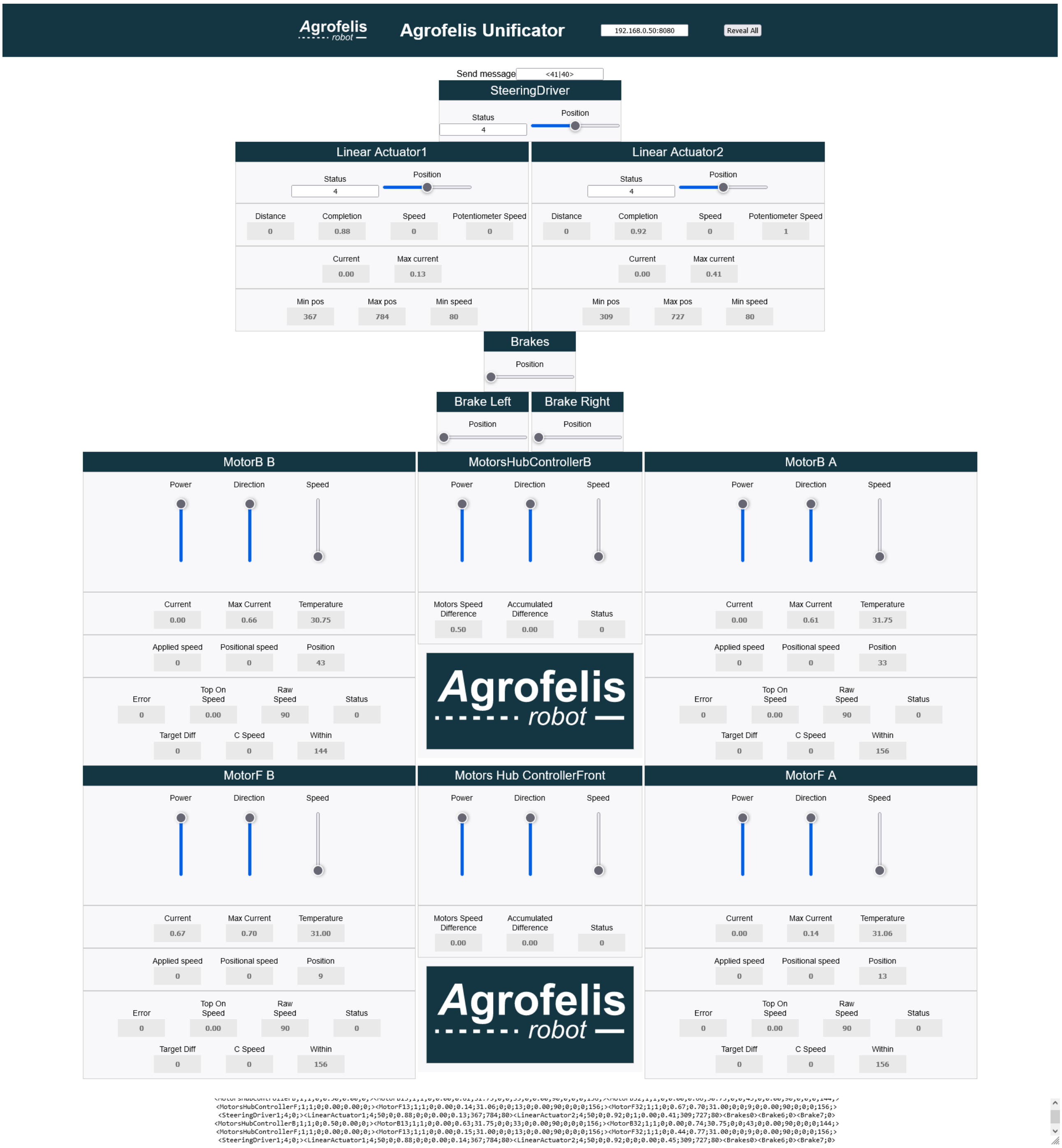


Figure 6: AgrofelisUnificator-snapshot

The Unificator web application, following the pattern established by the Motors Hub Controllers, enables the combination of multiple individual modules into one web application, providing a comprehensive overview of the entire system. The application source code can be accessed from the following path.

- AgrofelisUnificator.html

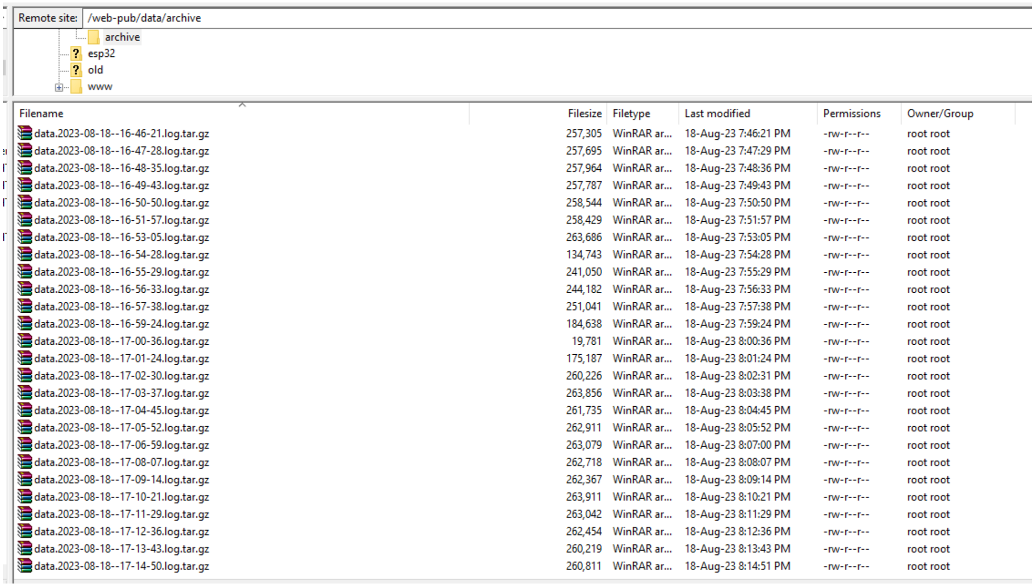
The HTML file also utilizes the following assets:

File	Description
styles.css	Defines the CSS styles of the web application.
motorsHubController.js	Establishes a WebSocket connection with the related IP of the module. Parses the HTML to identify the related sensors and actuators. Listens for interface changes as well as WebSocket messages and accordingly reflects or submits the related information.
agrofelis_logo_white_web.svg	The scalable vector graphic logo of the project.
jquery.min.js	Minified JS library dependency JQuery.

Special care has been devoted to ensure that the setup and code are very lightweight, clean and straightforward in order to be easily modifiable, assisting the rapid prototyping.

Archived Data

The following screenshot shows the data log files archived by the Unificator server along with their size.



Remote site: /web-pub/data/archive

archive
esp32
old
www

Filename	Filesize	Filetype	Last modified	Permissions	Owner/Group
data.2023-08-18--16-46-21.log.tar.gz	257,305	WinRAR ar...	18-Aug-23 7:46:21 PM	-rw-r--r--	root root
data.2023-08-18--16-47-28.log.tar.gz	257,695	WinRAR ar...	18-Aug-23 7:47:29 PM	-rw-r--r--	root root
data.2023-08-18--16-48-35.log.tar.gz	257,964	WinRAR ar...	18-Aug-23 7:48:36 PM	-rw-r--r--	root root
data.2023-08-18--16-49-43.log.tar.gz	257,787	WinRAR ar...	18-Aug-23 7:49:43 PM	-rw-r--r--	root root
data.2023-08-18--16-50-50.log.tar.gz	258,544	WinRAR ar...	18-Aug-23 7:50:50 PM	-rw-r--r--	root root
data.2023-08-18--16-51-57.log.tar.gz	258,429	WinRAR ar...	18-Aug-23 7:51:57 PM	-rw-r--r--	root root
data.2023-08-18--16-53-05.log.tar.gz	263,686	WinRAR ar...	18-Aug-23 7:53:05 PM	-rw-r--r--	root root
data.2023-08-18--16-54-28.log.tar.gz	134,743	WinRAR ar...	18-Aug-23 7:54:28 PM	-rw-r--r--	root root
data.2023-08-18--16-55-29.log.tar.gz	241,050	WinRAR ar...	18-Aug-23 7:55:29 PM	-rw-r--r--	root root
data.2023-08-18--16-56-33.log.tar.gz	244,182	WinRAR ar...	18-Aug-23 7:56:33 PM	-rw-r--r--	root root
data.2023-08-18--16-57-38.log.tar.gz	251,041	WinRAR ar...	18-Aug-23 7:57:38 PM	-rw-r--r--	root root
data.2023-08-18--16-59-24.log.tar.gz	184,638	WinRAR ar...	18-Aug-23 7:59:24 PM	-rw-r--r--	root root
data.2023-08-18--17-00-36.log.tar.gz	19,781	WinRAR ar...	18-Aug-23 8:00:36 PM	-rw-r--r--	root root
data.2023-08-18--17-01-24.log.tar.gz	175,187	WinRAR ar...	18-Aug-23 8:01:24 PM	-rw-r--r--	root root
data.2023-08-18--17-02-30.log.tar.gz	260,226	WinRAR ar...	18-Aug-23 8:02:31 PM	-rw-r--r--	root root
data.2023-08-18--17-03-37.log.tar.gz	263,856	WinRAR ar...	18-Aug-23 8:03:38 PM	-rw-r--r--	root root
data.2023-08-18--17-04-45.log.tar.gz	261,735	WinRAR ar...	18-Aug-23 8:04:45 PM	-rw-r--r--	root root
data.2023-08-18--17-05-52.log.tar.gz	262,911	WinRAR ar...	18-Aug-23 8:05:52 PM	-rw-r--r--	root root
data.2023-08-18--17-06-59.log.tar.gz	263,079	WinRAR ar...	18-Aug-23 8:07:00 PM	-rw-r--r--	root root
data.2023-08-18--17-08-07.log.tar.gz	262,718	WinRAR ar...	18-Aug-23 8:08:07 PM	-rw-r--r--	root root
data.2023-08-18--17-09-14.log.tar.gz	262,367	WinRAR ar...	18-Aug-23 8:09:14 PM	-rw-r--r--	root root
data.2023-08-18--17-10-21.log.tar.gz	263,911	WinRAR ar...	18-Aug-23 8:10:21 PM	-rw-r--r--	root root
data.2023-08-18--17-11-29.log.tar.gz	263,042	WinRAR ar...	18-Aug-23 8:11:29 PM	-rw-r--r--	root root
data.2023-08-18--17-12-36.log.tar.gz	262,454	WinRAR ar...	18-Aug-23 8:12:36 PM	-rw-r--r--	root root
data.2023-08-18--17-13-43.log.tar.gz	260,219	WinRAR ar...	18-Aug-23 8:13:43 PM	-rw-r--r--	root root
data.2023-08-18--17-14-50.log.tar.gz	260,811	WinRAR ar...	18-Aug-23 8:14:51 PM	-rw-r--r--	root root

Figure 7: Archived Log DataImage

The subsequent screenshot showcases the content of the two files contained in each archive, one for the Lidar data and one for all other modules.

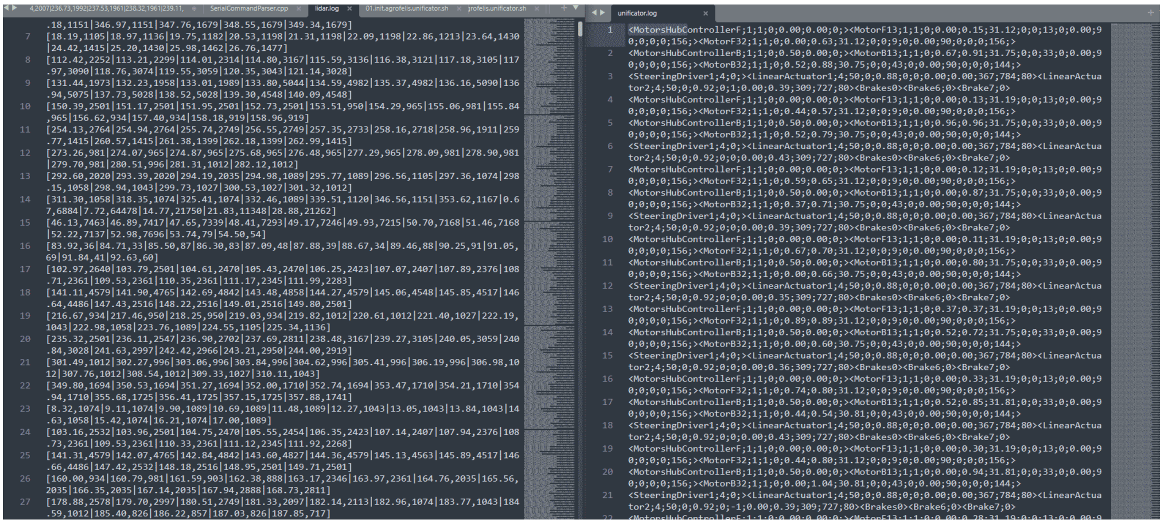


Figure 8: UnificatorAndLidarData

Agrofelis Network

In order to interconnect the various WiFi-capable modules of the robot, a compact access point module was employed. More specifically, the TP-LINK TL-WR802N v4 wireless router, supporting up to 300Mbps bandwidth, was chosen. This module was chosen due to its compact size, its capacity to operate in multiple modes as well as its 5V compatibility.

Figure 9: Wifi router

The wireless router is configured as a wireless router leading to a stable WiFi network and is used to associate the different modules with static IP addresses based on their unique MAC addresses. The WiFi network is secured with a password, which is also set for modules wishing to connect to the Agrofelis Network.

The default WiFi password followed by all WiFi modules of this repository is:

```
felisagrofelistobor_
```

The complete configuration of the WiFi router, as exported by its web application, has been persisted in the following path.

- tplinkWR802N_conf_wirelss_Router.bin

Additionally, the module was evaluated in "wisp" mode, allowing it to relay the WiFi of a mobile phone hot-spot to the Agrofelis Network. In this mode, the network's stability depended on the mobile internet connection and was avoided during field missions. Instead, it was primarily used to provide internet access to the system during maintenance.

The complete configuration of the WiFi router in "wisp" mode, as exported by its web application, has been persisted in the following path:

- tplinkWR802N_conf_wisp.bin

The two modes can be swiftly interchanged by uploading the respective configuration file to the wireless router's web interface.

The attached configuration files also encode the IP associations of each WiFi module, according to its MAC address which is unique in the world. Therefore, these mappings should be changed accordingly after observing the MAC address of the employed WiFi-capable modules. Below, the association map defined for our devices, is provided as an example.

MAC Address	IP Address	Name
48:B0:2D:2F:25:FA	192.168.0.50	Jetson Nano
A0:20:A6:2E:C8:8C	192.168.0.51	Power module A
60:01:94:7D:1C:BF	192.168.0.52	Power module B
A0:B7:65:61:53:84	192.168.0.55	Motors hub back
A0:B7:65:61:7D:7C	192.168.0.56	Motors hub front
24:0A:C4:1F:CF:50	192.168.0.60	Remote controller

Agrofelis USB Hub

A compact 5V USB hub is employed to enable multiple devices to be connected to the Jetson Nano. Specifically, the following modules are connected to the hub, which is subsequently connected to the USBv2 port of the computer.

- WiFi USB
- BMS USB sensor cable
- WiFi router
- Agrofelis steering module
- Agrofelis front Lidar sensors

Structural Support for Computing Modules

One often-overlooked aspect when arranging components is that their connection cables can occupy up to 50% more of their size. Although various connection cables can be made compact, this is not an option for USB cables, which could otherwise obstruct neighboring components. The solution designed to mitigate the identified problem, was four 3D-printed compact tilted mounts, allowing to pass the cables above the neighboring elements and to pass the cables through the space created underneath.

The following schematic illustrates the location of the computing modules, their extensions, the USB hub and the 3D-printed tilted mounts positioned above the steering plates in the back section of the robot.

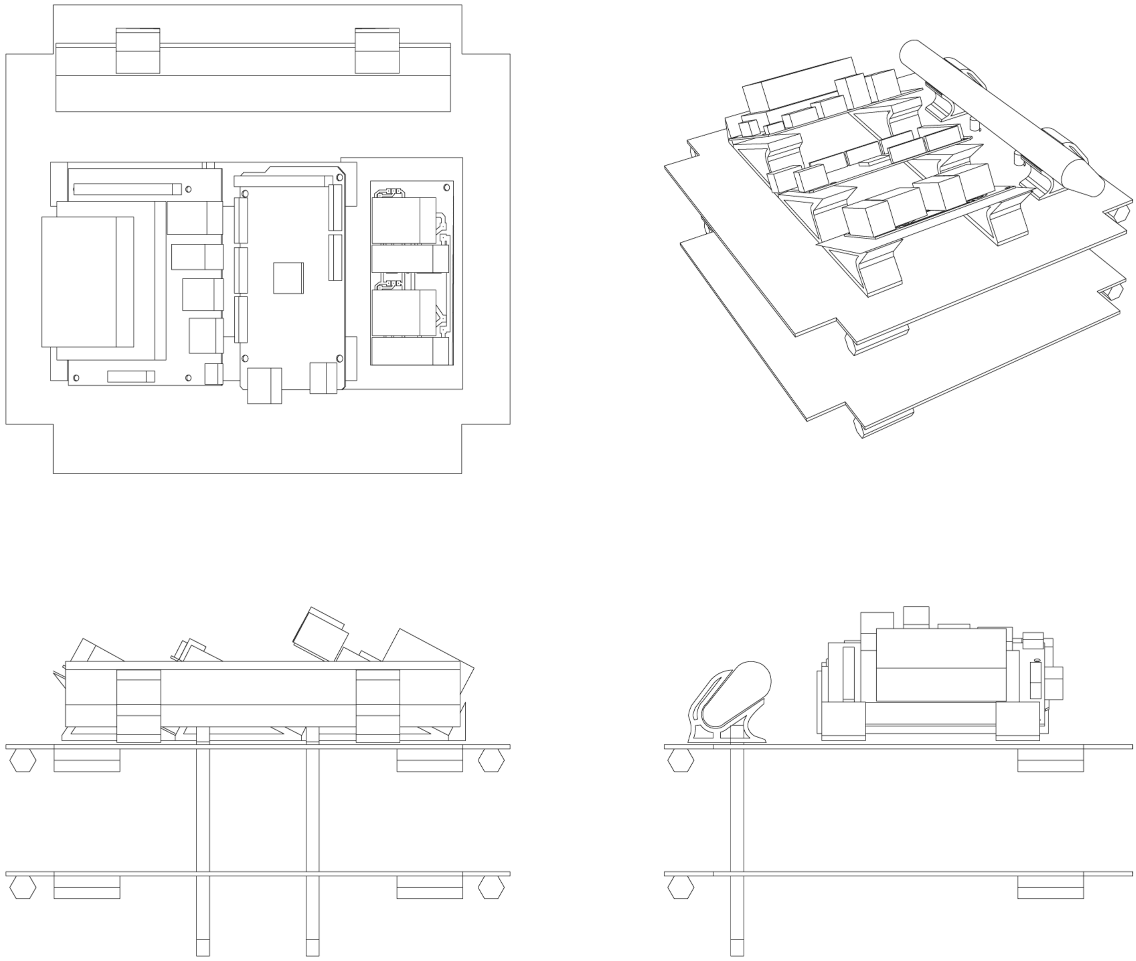


Figure 10: computing elements schematic

Two types of structures were designed and 3D-printed twice. The brackets and their arrangement on the steering plate can be seen in the following diagram.

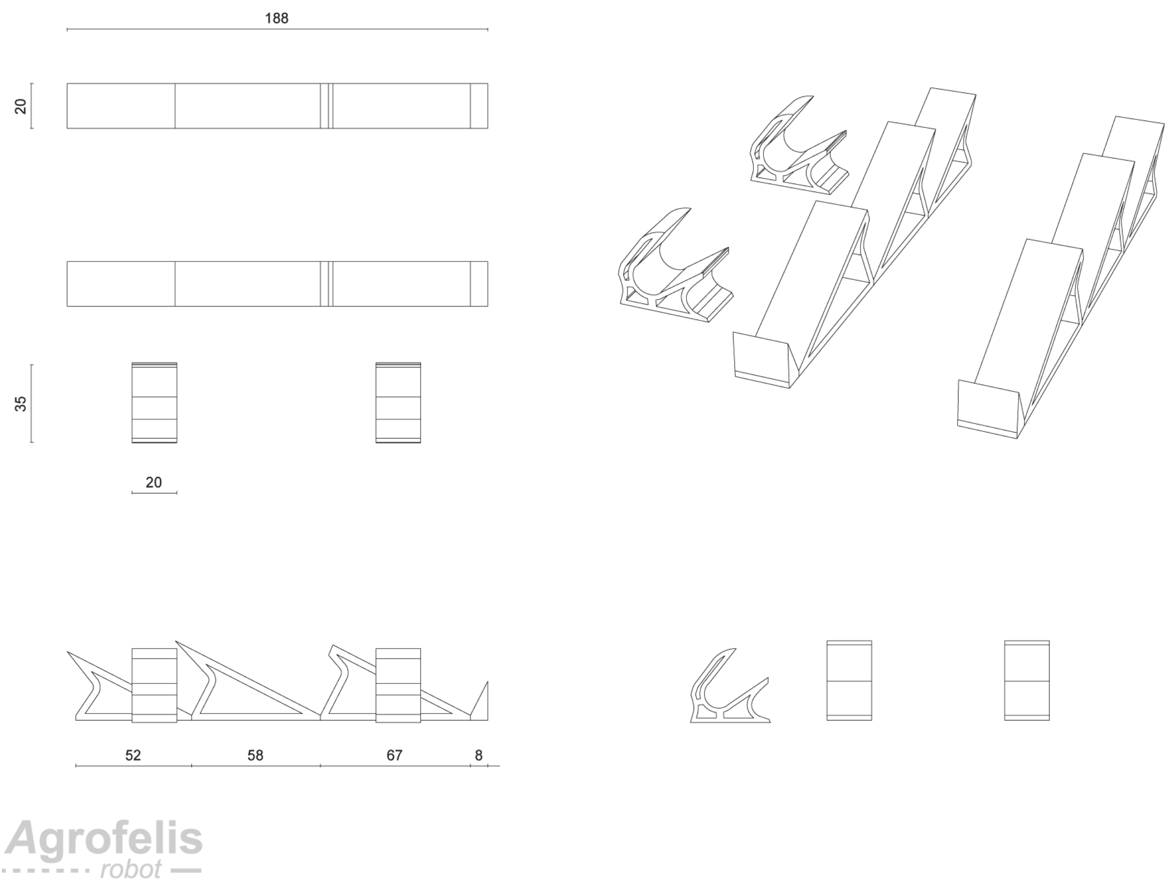


Figure 11: 3d printed brackets

The 3D printing source code files for manufacturing the related brackets, are listed by the following table.

Name	Standard Triangle Language file	Geometric Code
Computing modules tilted brackets	STL	Gcode
USB hub titled brackets	STL	Gcode

The following image shows the computing modules supportive structure and how the Jetson Nano is attached to it.

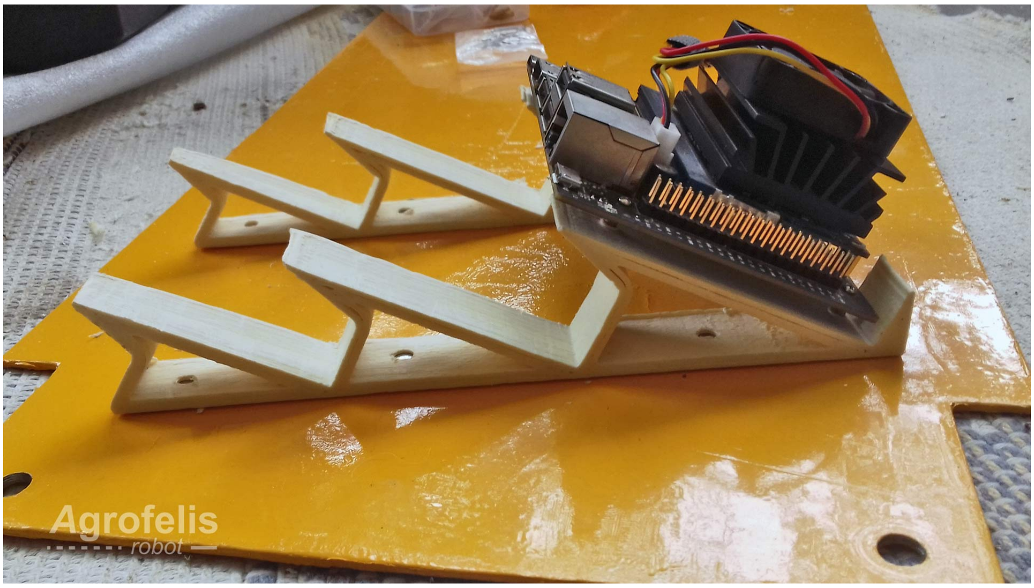


Figure 12: 3d print brackets-a

The use of magnets located on their bottom side, enables the structure to snap into place when in contact with the iron steering plate. The use of magnets also provides the ability to slightly relocate the modules if necessary. Despite the magnets not being strong enough to completely secure all components in place, the additional forces of multiple cables interconnecting the modules with the frame help keep the modules in place.

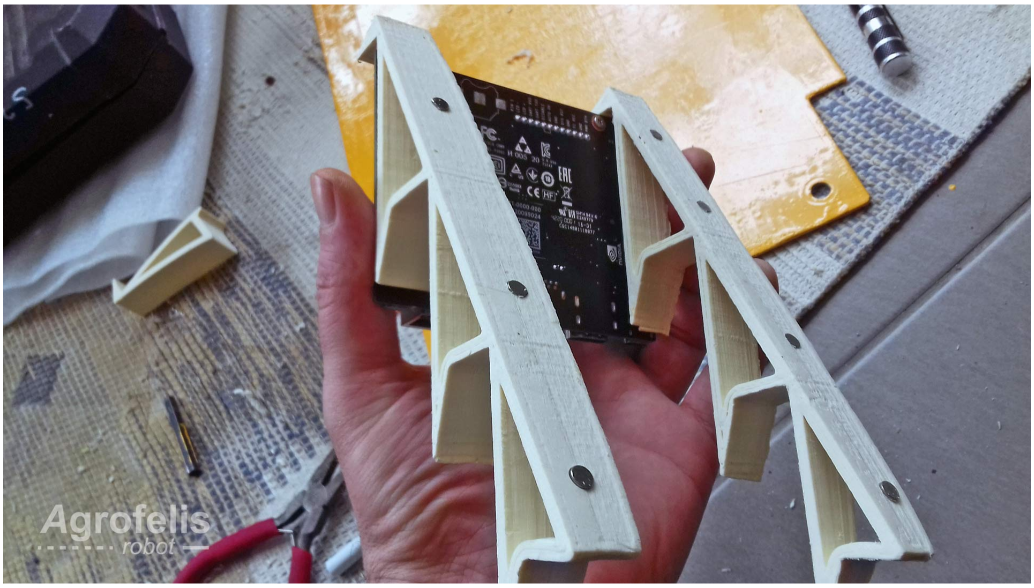


Figure 13: 3d print brackets-b

The following image showcases the Jetson Nano and the Arduino Mega attached to the related 3D-printed brackets.

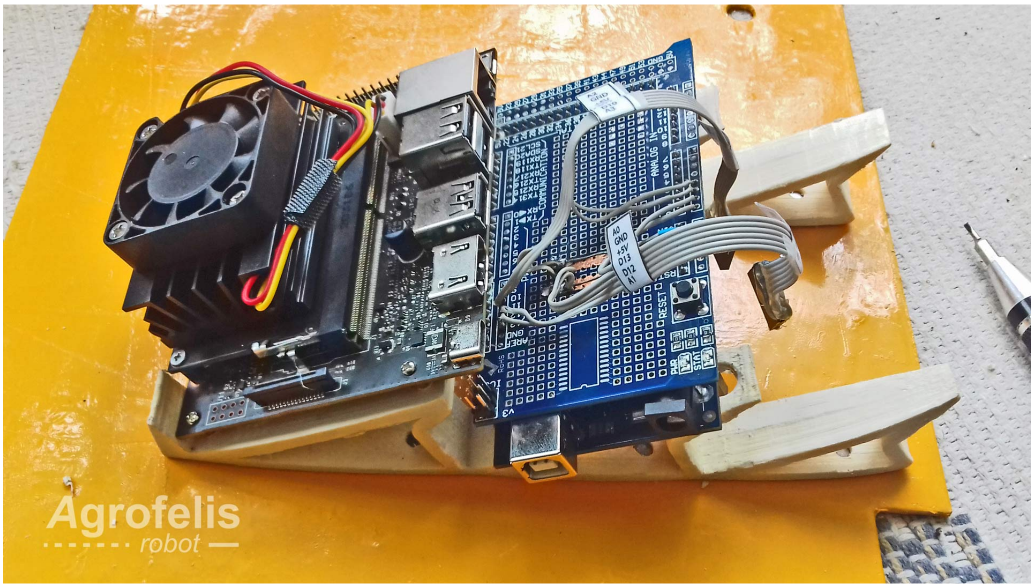


Figure 14: 3d printbrackets-c

A side view of the compilation demonstrates the degree of tilt, how a USB cable to be easily plugged into the Jetson Nano without being obstructed by the presence of the Arduino Mega. Also, the figure illustrates the space created to pass cables under the components towards the USB hub, and the minimum amount of material used to fabricate the brackets.

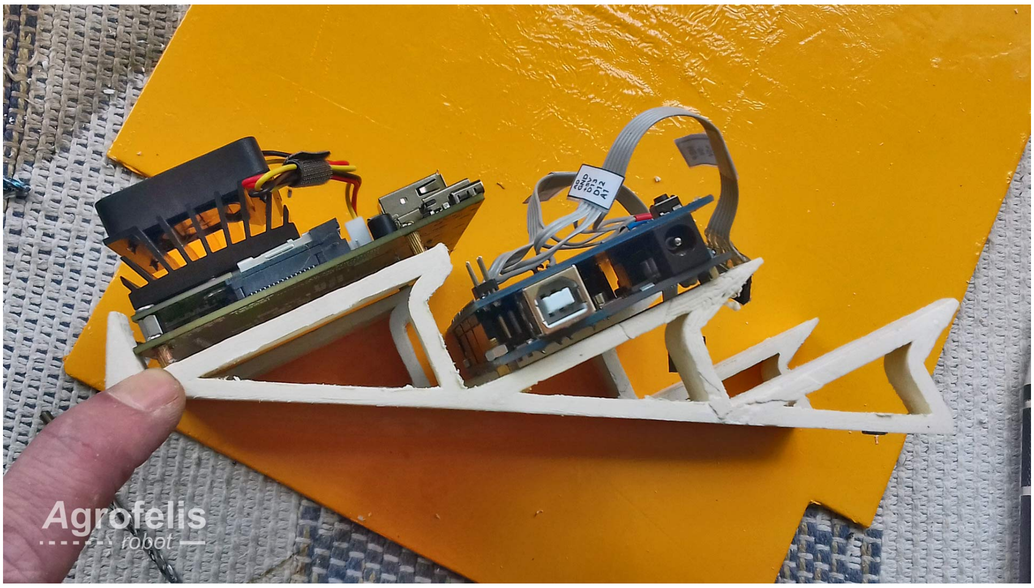


Figure 15: 3d print brackets-d

The following photos snapshot the computing modules' structure installed in the relevant compartment of the Agrofelis robot.

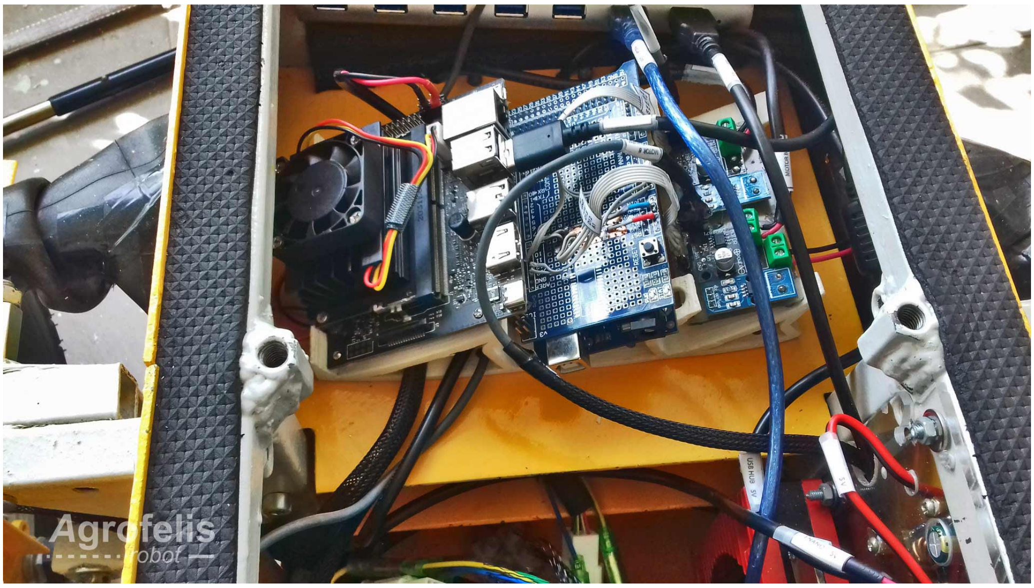


Figure 16: elements view-a

A front view photo of the compartment with its elements is provided below.

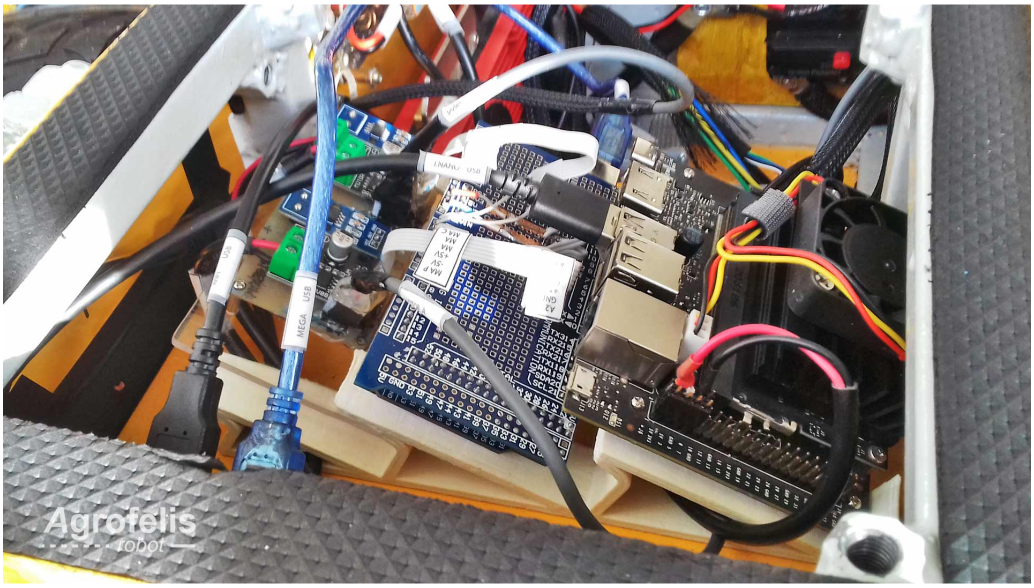


Figure 17: elements view-b

Computing and Network Components

The following table lists the individual components employed for manufacturing the Agrofelis computing modules and networking system. The index table includes moreover the product URLs, the indicative suppliers, as well as unit prices and sum totals.

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#1	NVIDIA Jetson Nano Developer Kit	Jetson Nano	Hellas Digital	1	199.00	199.00	-

No.	Product	Product URL	Supplier	Used Quantity	VAT Price (€)	Subtotal (€)	Note
#2	High speed ADATA premier one 128gb	Hard Disk	Skroutz	1	81.09	81.09	-
#3	Jetson nano fan	CPU Fan	Hellas Digital	1	8.00	8.00	-
#4	Jetson nano case	Jetson Nano Case	GRobotronics	1	15.80	15.80	Keeping latching buttons and camera mount
#5	Coral USB Accelerator	Coral	Nettop	1	87.90	87.90	-
#6	8 MP night vision camera	Camera	Hellas Digital	1	31.99	31.99	-
#7	TP-LINK TL-WR802N v4 Wireless Router	Wireless Router	Skroutz	1	24.30	24.30	-
#8	15 Pin Ribbon Flex CSI Cable 100cm	Flex CSI Cable	Aliexpress	1	0.67	0.67	-
#9	7 port USB v3.1 HUB	USB Hub	Skroutz	1	36.59	36.59	-
Total						**485.34**	

The total cost to manufacture the Agrofelis computing modules and network, exclusive of shipping and labor costs, amounts to approximately **485** euros.

Summary

The document presented an overview of the computing elements utilized in the Agrofelis robot. The developed services conterized via Docker were described and indexed. Additionally, the Agrofelis Unificator Software, which connects all Agrofelis modules, was introduced and its source code and features were presented. The lightweight 3D-printed structural elements designed for organizing the components and their cables source code files, were also provided. The document concluded with a list of the components used and indicative suppliers, aiding the replication of the Agrofelis computing and networking systems.

End of document