SQAT

SOIL QUALITY ANALYSIS TOOL

Deliverable 2.6

User manual for System using SQAT Robots

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Disclaimer

The author of this document has taken any available measure to ensure that the information contained in this document is accurate, consistent, lawful, and up to date.

Executive Summary

Farms are at the forefront of the data economy, propelled by digitalisation, robotics, and smart algorithms. However, these advancements exacerbate societal pressures on soil health, demanding cleaner water, healthier soils, increased carbon storage and biodiversity. Current solutions are costly and unsuitable for farmers. With this in mind, the EU-funded SQAT project will develop a smart soil mapping service. Combining multi-level, multi-technology approaches, SQAT offers high-resolution soil property maps and tailored solutions for farmers. Using autonomous robot-mounted sensors and innovative in situ analysis tools, the SQAT system enhances productivity while reducing costs. Co-developing with SMEs, SQAT aims to commercialise its solutions, empowering farmers with variable-rate applications for liming, fertilisation, seeding, tillage, and carbon farming.

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Abbreviations

ABE	Association of Balkan Eco-Innovations
AGRILAB	Agrilab limited liability company
ATB	Leibniz Institute of Agricultural Engineering and Bioeconomy e.V.
AWD	All-wheel Drive
EC	European Commission
EV ILVO	Eigen vermogen van het instituut voor landbouw-en visserijonderzoek
HSG-IMIT	Hahn-schickard-gesellschaft fur angewandte forschung ev
ILT-OST	Institute for Lab Automation and Mechatronics
OFI	Officine innovazione s.r.l.
TERRATMD	Terra controlling tmd d.o.o
VDBORNE	Van den borne projecten bv
WP	Work Package

1 Introduction

1.1 General information

This user document bundles the three user manuals for the robots developed and deployed during the SQAT project:

1. The SQAT heavy-weight sampling robot developed by ILVO.
2. The SQAT continuous mapping robot developed by Exobotic.
3. The SQAT lightweight sampling robot developed by OST-ILT.

The respective manuals apply exclusively to the respective robots. This manual reflects the current state of the robot systems at the time of writing. As the robots are still under active development and testing, both hardware and software components may undergo significant changes.

Certain machinery and its components described in this report are prototypes developed within the SQAT project and are intended solely for research purposes. As such, they do not bear the CE marking and are covered under the exemption specified in Article 3(1)(m) of Regulation (EU) 2023/1230 on machinery products:

“Machinery or related products specially designed and constructed for research purposes for temporary use in laboratories.”

These prototypes must be handled exclusively by a trained operator in coordination with the developers. Use is restricted to controlled research settings, and operators must have completed appropriate training, documented by participation in designated training events.

Despite their current status as research prototypes, all developments are being carried out in alignment with relevant EU directives and regulations, using harmonized standards and completing a risk analysis, to achieve CE conformity upon completion of the SQAT project.

Consequently, this manual is subject to revision and will be updated accordingly to reflect future developments. Users are advised to refer to the latest version for the most up-to-date information. To ensure this and for detailed information beyond mentioned in this manual, users are advised to contact the appropriate SQAT technology partner (ILVO, Exobotic, ISF-OST), responsible for the development of the specific robot used.

1.2 Reading and understanding this manual

This manual intends to inform users and enable them to safely and efficiently operate and service the robots. Users must carefully read the manual before using the machine. Furthermore, specific training may be required before operating the robots. In case of any doubt or uncertainty, please contact the manufacturer (see contact information in sections 2.1.1, 3.1.1, and 4.1.1). Special attention must be paid to all safety-related information.

1.3 Common abbreviations in this manual

Abbreviation	Definition
SQAT	Soil Quality Analysis Tool
PLC	Programmable Logical Controller
RTK	Real-time Kinematic
GNSS	Global Navigation Satellite System
VDC	Volt Direct Current

2 SQAT heavy-weight sampling robot

2.1 General information

2.1.1 Manufacturer contact information

General contact
Flanders Research Institute for Agriculture, Fisheries and Food (ILVO), Technology & Food Department
Burg. Van Gansberghelaan 115 box 1
9820 Merelbeke-Melle, Belgium
Mail: info@agrifoodtechnology.be

2.1.2 Purpose, structure, and function of the robot

The SQAT heavy-weight sampling robot is specifically designed for autonomous soil sampling applications with the MP4.100 soil sampler by Bodenprobetechnik Peters within a precision crop farming context. The robot should be exclusively used for this purpose; the robot cannot be used for any other purposes without the explicit written consent of ILVO. The main components of the robot are illustrated in Figure 1. The robot is composed out of three different systems:

1. Carrier vehicle,
2. Soil sampling device,
3. Vertical penetrometer.

The **carrier vehicle** (robot platform) is built around a central frame equipped with independent double A-arm suspension for each wheel. It is fully electric, powered by a $LiFePO_4$ (Lithium Iron Phosphate) battery pack. Both the front and rear wheels are driven by electric motors coupled to differentials, enabling all-wheel drive (AWD) functionality. Steering is implemented on both axles via electric servomotors actuating dedicated steering racks. This significantly reduces the robot's turning radius, thereby enhancing its manoeuvrability in obstacle-dense environments such as orchards or vineyards. A hydraulic system with pump powered by an electric motor is foreseen to power the soil sampler. The robot platform can be operated manually through a remote controller or autonomously (through RTK-GNSS). The vehicle is equipped with safety bumpers, emergency stops, and a safety LiDAR system to ensure operational safety.

The **soil sampler** is a fully autonomous soil sampler (MP4.100) designed and developed by Bodenprobetechnik Peters. The sampler equips a gauge auger that is hammered into the soil to extract samples up to 1000 mm deep and separate them into maximum four different containers. The implement is hydraulically powered by the robot; additionally, a 12V connection is supplied for powering the control unit and hydraulic valves. Sampling parameters such as sampling speed, sampling depth, layer separation, etc., can be adjusted by the machine's operating screen. The soil sampler is designed and built exclusively for off-road agricultural use. It is forbidden to use this machine on paved surfaces, on roads, and on roadsides. When using this device on agricultural fields, the gauge auger is driven into the ground to a depth of 1060 mm. Before each use, it must also be ensured that no underground pipes such as water, gas, electric- or oil pipes etc. are present to prevent damage while the soil sampler is used.

The vertical **penetrometer** is used for cone resistance measurements for mapping soil compaction in agricultural fields. The device uses an electrical actuator to push a rod with a standardised cone (1mm², 30°) into the soil while measuring mechanical resistance through a load cell. When using this device, the cone is pushed with a force of up to 2000 N to a depth of 1000 mm. Before each use, it must also be ensured that no underground pipes such as water, gas, electric- or oil pipes etc. are present to prevent damage while the penetrometer is used.

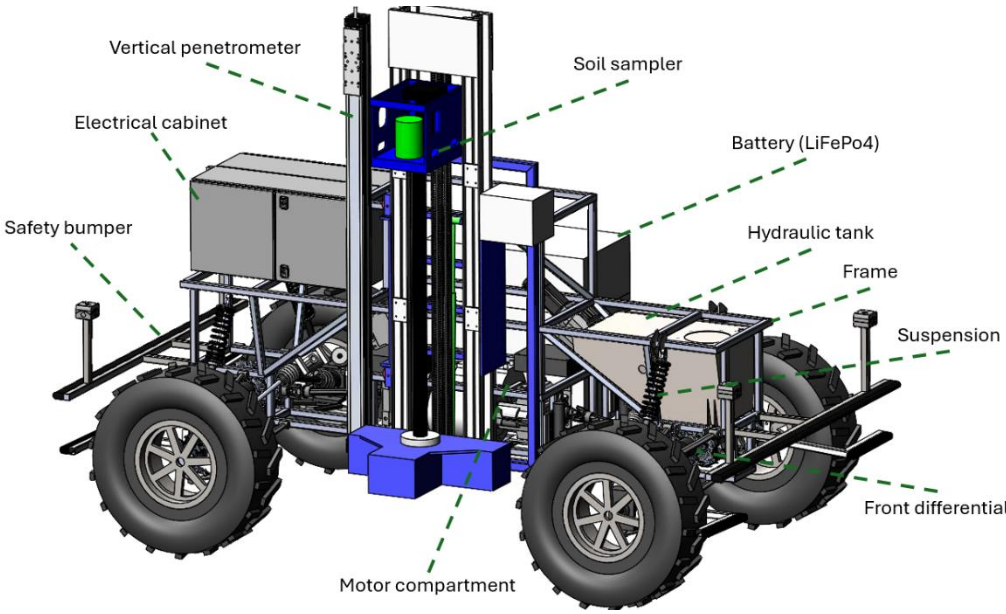


Figure 1.1. Illustration of the SQAT heavy-weight sampling robot composed of (1) the carrier vehicle; (2) the soil sampling device; (3) the vertical penetrometer.

2.1.3 Technical specifications

Carrier vehicle

Manufacturer	ILVO
Dimensions	
Empty weight	1200 kg
Track width	1450 mm (centre to centre)
Length	3200 mm
Height	2300 mm
Ground clearance	320 mm
Operational specifications	

Motor power	2x 12 kW drivetrain (nominal) 2x 1kW steering (nominal) 6 kW hydraulic system (nominal)
Wheel diameter	760 mm
Tire pressure (max rating) in cold conditions	1.1 bar (2.5 bar)
Software system	High level control: ILVO ARTOF open-source framework Low level control: Siemens PLC
Maximum forward velocity	15 km/h
Traction force	5270 N (nominal) 11780 N (maximal)
Hydraulic system	
Oil pump pressure (max)	150 bar
Hydraulic pump displacement	10.2 cc
Hydraulic fluid (volume)	HVLP 46 (50 l)
Battery	
Battery capacity	45 kWh
Battery chemistry	LiFePo4
Nominal battery voltage	51.2 VDC
Maximum charge current (output onboard charger)	70A

Soil sampling device – MP4.100

Manufacturer	BODENPROBETECHNIK PETERS GMBH
Dimensions	
Weight	215 kg
Height	2050 mm
Width	850 mm

Depth	760 mm
Operational specifications	
Power supply	12 VDC
Drilling depth	1080 mm
Test depth	1000 mm
Number of blows (hydraulic hammer)	2200 blows/min
Single blow energy (hydraulic hammer)	40 Joule
Sound pressure/sound power (hydraulic hammer)	93/105 dB
Hydraulic system	
Hydraulic flow (max)	20 l/min
Working pressure (max)	135 bar
Oil return back pressure (max)	10 bar

Vertical penetrometer

Manufacturer	ILVO
Weight	100 kg
Height	1500 mm
Test depth	1000 mm
Max. sampling force	2000 N

2.2 Safety instructions

The SQAT heavy-duty sampling robot has been designed and constructed based on a comprehensive risk assessment and with reference to relevant harmonized standards and technical specifications. As such, it reflects the current state of the art and has been developed with safety as a primary consideration.

However, this robot platform remains a prototype and is currently in the research and development phase. It has not yet undergone CE conformity assessment and therefore does not have the CE marking.

Operation of the robot is restricted to trained operators who have participated in an official training event and have read and fully understood this manual and its safety instructions.

The robot must be operated with caution and under continuous supervision to ensure that all safety measures are correctly implemented and adhered to during use.

The robot is equipped with several safety features to protect users and bystanders from dangerous situations during the manual and autonomous use of the machine. All safety components and warning labels must remain intact and unaltered.

! The robot must be used exclusively for its intended purpose and may not be modified without the manufacturer's permission.

! The robot must always be powered off before performing maintenance tasks.

! The robot may only be used on private property and should be transported on public roads using a road-compliant trailer.

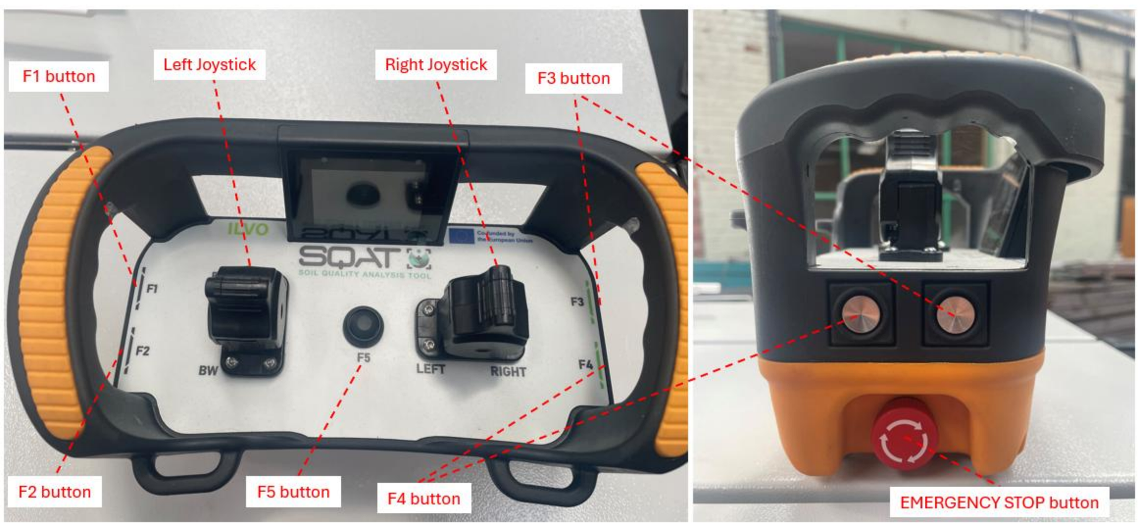
! Only trained operators who have followed the official training event and have thoroughly reviewed and understood the user manual can operate, maintain, or repair the machine. Maintenance and repair are done in direct correspondence with the developers.

! All safety-related parts and warning notices attached to the machine have not been removed or tampered with.

2.2.1 Safety devices and their function

1. **The emergency stop buttons - located on the electrical cabinet below the operation screen and on both sides of the front and rear safety bumper (Figure 2).**
   Pressing one of these button engages Safety mode, ensuring user safety in case of an unsafe situation. All actuations will stop immediately, motor power will be cut, and the brakes will engage.

2. **The remote emergency stop button - located on the right side of the robot's remote controller.** Pressing this button engages Safety mode and ensures user safety in case of an unsafe situation. All actuations will stop immediately, motor power will be cut, and the brakes will engage.



3. **Light indicator – located on top of the electrical cabinet**
   The color of the indicator lamp reflects the current state of the robot:
   - Purple – Stationary mode. All actuation is allowed except for driving or steering. This status ensures the robot is stationary during soil sampling or performing cone resistance measurements.
   - Green - Manual mode, slow operation. The robot can be driven using the remote controller joysticks in a slow way.

- Blue - Manual mode, fast operation. The robot can be driven using the remote controller joysticks in a fast way.
- Yellow - Autonomous mode. The robot is operating fully autonomously. The LiDAR will be engaged in this modus for obstacle awareness.
- Red – Safety mode, operation is disabled, or an error occurred. No power is provided to the actuators.

4. **Safety bumpers - located at the front and rear and in front of each wheel**
   If the robot contacts an external object through one of its safety bumpers, the safety bumper is pressed inwards, triggering an emergency stop in the robot's operating system. This event will engage Safety mode.
5. **LiDAR sensor - located at the front**
   When an object is detected near the front of the robot in Autonomous mode, the LiDAR sensor activates a ramp down of the velocity in the first zone and triggers an emergency stop in the robot's operating system in the second zone. The LiDAR sensor is disabled in Manual mode for maximal flexibility while manoeuvring. The LiDAR is specifically suited for outdoor applications.

Warning: Although safety bumpers and a LiDAR sensor are used for obstacle detection, some obstacles may not be detected by the robot (e.g. fencing wires), resulting in material damage during operation. The operator is responsible for driving the robot in Manual mode and setting up and verifying the trajectory for autonomous operation in Autonomous mode.

2.2.2 Machine safety markings

As of the current development stage, the robot does not yet include finalized safety markings or warning labels. The system is still undergoing testing and validation, and all applicable safety labelling in accordance with standard machinery directives will be added prior to release.

Warning: Until all safety labels are applied, the system must only be operated by qualified personnel familiar with its hazards and functions.

2.2.3 Residual risks

When in manual mode it is solely up to the operator to safely control the robot and its subsystems. The LiDAR is only engaged in Autonomous mode. Although other safety mechanisms remain active, the robot no longer anticipates obstacles based on sensor data. It is therefore up to the operator to continuously assess the surroundings and make appropriate adjustments to the robot's speed and direction to avoid hazardous or unintended situations. The operator should operate with heightened awareness when in manual mode, especially in dynamic environments. There is a risk of pinching, crushing and minor bodily injuries. Ear protection should be used when standing close to the robot when soil sampling.

2.3 Robot operation

2.3.1 Inspection before use

Carrier vehicle

- Check the correct tyre pressure and check for tire wear or damage to the rims or tires (see 2.4.1).
- Check the oil level of the hydraulic system and ensure there is no trace of leaking oil.
- Check the maintenance interval on the lubrication (2.4.3) and the hydraulic system (2.4.6), with the current values for operating hours and travelled distance, visible on the dashboard robot operation screen.
- Check the brake pads and condition of the braking system (2.4.4)
- Check for loose mechanical parts, including bolts, nuts, fasteners, and structural connections. Tighten any components that appear to be unsecured.
- Inspect all electrical cables, fuses and connectors for signs of damage, such as cuts, abrasions, or wear. No copper conductors should be exposed at any point. All insulation must be fully intact. Ensure all connectors are securely fastened and that cables are properly routed and supported. Check for signs of overheating, discoloration, or corrosion near terminals and connections.
- Inspect all hydraulic hoses and fittings for cracks, bulges, abrasions, or leaks. Ensure there are no visible signs of material fatigue, hardening, or fluid leakage. Hoses must be properly clamped and routed to avoid kinking or excessive bending, especially near connection points. All hydraulic connections must be tight and free from oil residue.

Soil sampling device

- Check whether the impact system is sufficiently lubricated (see 2.4.7.2).
- Check the gauge drill for damage or excessive wear, replace the gauge drill when needed.
- Check the scraper for wear and ease of movement.
- Check the tension of the duplex chain as part of normal maintenance and lubricate the chain if needed (see 2.4.7.3).
- Check for loose mechanical parts, including bolts, nuts, fasteners, and structural connections. Tighten any components that appear to be unsecured.
- Ensure all connectors are securely fastened and that cables are properly routed and supported.
- Inspect all hydraulic hoses and fittings for cracks, bulges, abrasions, or leaks. Ensure there are no visible signs of material fatigue, hardening, or fluid leakage. Hoses must be properly clamped and routed to avoid kinking or excessive bending, especially near connection points. All hydraulic connections must be tight and free from oil residue.

Vertical penetrometer

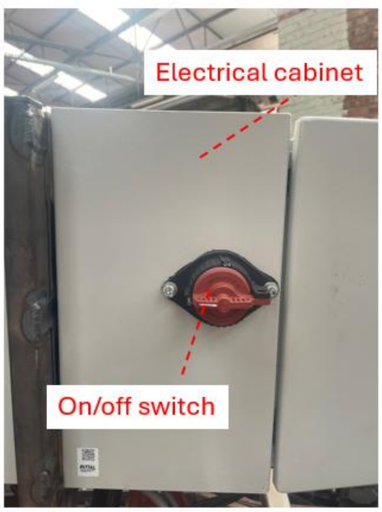
- Check that the measuring rod is not bent.
- Check the penetration cone for damage or excessive wear. Replace the cone if its diameter is less than 11 mm (measure using a calliper).
- Ensure all connectors are securely fastened and that cables are properly routed and supported.
- Check for loose mechanical parts, including bolts, nuts, fasteners, and structural connections. Tighten any components that appear to be unsecured.

2.3.2 Setup and manual robot operation

Before use, it is important to ensure that the batteries are sufficiently charged for the task at hand (see 2.4.5) and that the emergency stop button of the robot is released.

The following steps describe how to **power on and manually operate** the robot:

1. Power on the robot by turning the red key on the back of the electrical cabinet half a turn to the right, and allow approximately one minute for start-up.
2. Release the emergency stop on the remote controller, and press and hold the button on the right side of the remote controller for 2 seconds. The remote controller should now be connected.
3. Use the left joystick of the remote controller to move the robot forward and backward.
4. Use the right joystick of the remote controller to steer the robot left and right.
5. Press the F1 button to toggle between fast (blue indicator light) and slow (green indicator light) manual operation modes.
6. Use the operation screen to change specific robot parameters.



2.3.3 Autonomous robot operation

The following steps describe how to **autonomously operate the robot**:

1. After powering on the robot, connect your laptop or tablet to the robot's Wi-Fi network.
2. Open a browser and navigate to the robot's ARTOF operation software by entering the following address: http://sqat
3. In the software interface, click the **New Field** button in the top right corner.
4. Upload the following shapefiles: a trajectory (line shapefile), a task (point shapefile), and a geofence (polygon shapefile). Each shapefile consists of 5 component files, which all must be uploaded. After uploading, confirm by clicking the green checkmark. Define the task as **'soil sampling'** or **'penetrometer'**; both are '**discrete'** tasks.
5. Manually drive the robot to the starting point of the trajectory using the remote control of the robot.

6. Define the desired soil sampler (number of layers, depth of layers, etc.; see 2.3.4) or penetrometer (cone diameter, insertion speed, insertion depth) settings on the robot's operation screen.
7. Before enabling Autonomous mode, ensure that the desired operating area of the robot is safe. The robot must be only used on private area and is solely intended for soil sampling and cone resistance measurements on agricultural fields. Make sure no public roads, trails or paths cross the intended robot trajectory. Pay special attention to public roads, keep sufficient distance between the trajectory and the road, especially in corners. Ensure also sufficient distance to steep hills, ditches etc.
8. Push the F1 button until Autonomous mode is engaged (yellow indicator light). Push the F5 button on the remote controller to start Autonomous mode (an audible signal will sound). The robot will now start executing its task, autonomously and automatically taking soil samples and/or perform cone resistance measurements.
9. After completion of the task, an audible signal will sound, the robot will enter Safety mode (the indicator light will turn red). In the software interface, a message will occur signalling the end of the trajectory is reached.

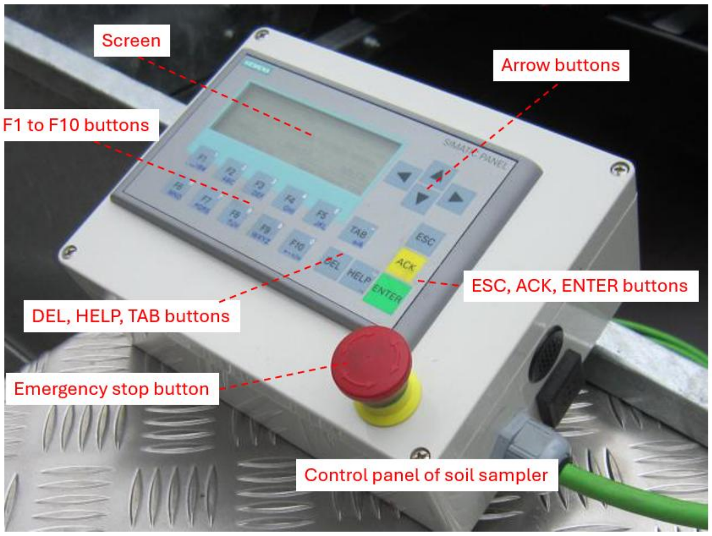
2.3.4 Manual soil sampling operation

Instead of autonomous soil sampling, the robot can also be operated manually to take soil samples. Below, the manual sampling process is briefly described. For more detailed instructions, please refer to the user manual of the MP4.100 soil sampler.

Note: While the robot is operated manually, the soil sampler itself still runs in automatic mode.

1. First, navigate the robot to the desired sampling location and ensure it is completely stationary before starting the sampling process. Engage the Stationary status (purple indicator lamp color) of the robot by pressing F1 on the robot remote controller.
2. On the control panel of the soil sampler: Begin by pressing the F3 button, which will open the first page of the automatic mode interface. On this page, the sampling horizons can be configured: use the arrows to select a field, delete the current value using the DEL key, enter a new numerical value, and confirm with ENTER. The number of horizons can also be set: choosing “4” results in one mixed sample with four separate layers; “2” results in two mixed samples with two layer separations; and “1” results in four mixed samples without layer separation. The field to the right of the sampling depth allows the user to indicate whether a specific horizon should be discarded or still assigned in case the target depth is not reached. After configuring the horizons, press F3 again to access the second page of automatic mode. The sampler will now move to its initial position in preparation for operation.
3. Press F6 to initiate the extraction process. The robot will remain in Stationary mode during the measurement.
4. When finished, engage the Manual mode of the robot by pressing F1 on the robot remote controller (green or blue indicator lamp color).
5. Move the robot to the next location and engage Stationary mode by pressing F1 (purple indicator lamp color). Press F6 on the control panel of the soil sampler, an additional sample is taken to be part of the current mixed soil sample.

Warning: While hammering, the sound power level can reach up to 105 dB. Wear hearing protection to prevent hearing damage!



Note: Function key F7 is used either for one layer without layer separation or for two layers with layer separation. In the first case, pressing F6 starts each sample as part of one mixed sample, and the first mixed sample is collected in container I. Pressing F7 shifts the next mixed sample to container II, and so on. In the second case, the samples are divided between container I (upper layer) and container II (lower layer). Pressing F7 shifts the magazine, after which the next samples are placed into container III (upper layer) and IV (lower layer) as one mixed sample.

Note: The entire extraction process can be cancelled at any time by pressing F9. Pressing and holding F10 for five seconds resets the counters (number of punctures, discarded punctures, and saved depths) and returns the system to container I. For the MP-4.100 model, when sampling with two layers and separation, the F10 button must be pressed after the second sample, or after four samples without separation, to indicate the end of the sampling cycle.

2.3.5 Manual penetrometer operation

Instead of autonomous operation for cone resistance measurements, the robot can also be operated manually to measure penetration resistance. Below, the manual penetrometer process is briefly described.

Note: While the robot is operated manually, the penetrometer itself still runs in automatic mode.

1. First, navigate the robot to the desired sampling location and ensure it is completely stationary before starting the cone resistance measurement process. Engage the Stationary status (purple indicator lamp color) of the robot by pressing F1 on the robot remote controller.
2. Define the desired penetrometer settings on the robot's operation screen (see Section 2.3.3) and press 'Start'. The penetration resistance measurement will now begin. During the measurement, the robot will remain in Stationary status.
3. When finished, engage the Manual mode of the robot by pressing F1 on the robot remote controller (green or blue indicator lamp color).

4. Move the robot to the next location and engage Stationary mode by pressing F1 (purple indicator lamp color).

2.3.6 Remote monitoring

As of 28-07-2025, the remote monitoring and teleoperation tools are still in active development and subject to a lot of changes, as such it is not included in this manual.

2.3.7 Shut down

Press the emergency stop on the remote controller of the robot, this will engage Safety mode and disable the remote controller. Then, power off the robot by turning the key half a turn to the left. Verify that the indicator light is off.

2.4 Maintenance

2.4.1 Tires

The tire pressure should be checked regularly; this should be done in cold conditions. To optimize drive efficiency and minimize tire wear, the tires pressure should be 1.1 bar.

Replace the tires when the tire tread wear has reached the replacement mark or when the tire is damaged, e.g. due to an external impact. When the rim is damaged, the rim should be replaced as well. Replacement should only be done with the same wheel sizes (30 × 10.00 R14) and rims (14 × 7.0 AT). When mounting the rim, the bolts should be torqued to 100 – 120 Nm.

Warning: Always ensure that tall wheel bolts are tightened to the correct torque. Do not use lubricating oil or grease on wheel bolts. Excessive or insufficient tightening can cause wheels to come off during driving which can cause severe damage to equipment or personnel.

2.4.2 Suspension

The robot platform has individual dual wishbone (A-arm) suspension to ensure optimal vehicle dynamics during operation on agricultural terrains. The spring adjustment sleeve of the hydraulic shock absorber has 5 adjustment positions. The spring can be adjusted if necessary with the use of specific tools.

Warning: When adjusting the shock absorption position, all four shocks should be set to the same position. Failure to do so can result in uneven handling, reduced vehicle stability, and increased wear on suspension components.

2.4.3 Lubrication

The individual wheel suspensions and balance bar are equipped with grease fittings. These require sufficient lubrication with a suitable machine grease. The grease fittings should be greased every 800 km (maximal 2 pumps per interval). When lubricated, reset the respective counter in the dashboard of the operation screen.

The front and rear differential are lubricated with 260 ml transmission oil (SAE 80W-90 GL-5). This oil should be replaced after every 2000 km of driving. When the robot is used in more extreme conditions (very muddy or hilly terrain), the differential oil should be replaced every 25 hours. When serviced, reset the respective counter in the dashboard of the operation screen.

Pay attention for abnormal sounds originating from the drive system, which might indicate damage to driveshafts, differentials, etc.

If cuts, damage or grease leakage in the front and rear drive axle dust boots are present, the robot should be serviced, and operations should be halted.

2.4.4 Brakes

The robot is equipped with hydraulic disc brakes on all wheels. These brakes are only engaged when the robot is powered off, in Safety mode or in Stationary mode. During operation, the robot will brake on the drive motors.

Regularly check the brake system for leakage and check before use if the brake pads are worn, damaged or loose. Check the surface condition of the brake disks, ensure that no lubricants are applied to the brake pads. If needed, brakes should be cleaned using brake cleaner. The brake fluid levels must be controlled periodically as well. Care must be taken to keep the brake fluid at the recommended level (between the minimum and maximum indication) and not to overfill. The brake pads have a standard thickness of 5mm, when the thickness is lower than 1.5mm, the old brake pads should be replaced with original, new brake pads.

2.4.5 Battery

The robot is powered by a Lithium Iron Phosphate ($LiFePO_4$) **battery system**, selected for its optimal energy density, long cycle life, and high level of operational safety. This battery chemistry offers superior thermal and chemical stability, making it significantly less susceptible to thermal runaway or combustion compared to other lithium-based chemistries. The battery system comprises multiple 51.2V battery modules connected in parallel, each containing 16 cells in series. This configuration ensures a stable and efficient power supply for the robot's drive motors, steering mechanisms, and onboard electronics. The individual battery modules should only be opened by specifically trained personnel. The battery pack is permanently mounted within the chassis at a position optimized for balanced weight distribution and mechanical stability. The estimated number of battery cycles is visible on the dashboard of the robot. Unless damage to the battery cells occurs, e.g. due to overcharging or charging in freezing temperatures, the battery should last 8000 cycles (70% SoH). Battery replacement should only be performed by trained personnel.

Warning: The battery is designed to remain on its foreseen location on the robot. This location must not be altered under any circumstances, as this may compromise the robot's performance and safety, particularly on uneven terrain or during transport.

An integrated onboard **charger** is provided for safe and efficient battery charging. Charging must be carried out exclusively using this internal charger. This ensures a correct charging process, ensuring the right charging voltages and currents. Furthermore, it ensures charging the battery system as a complete unit, to prevent uneven charging between individual battery modules. Uneven charging of the individual batteries could result in high cross-battery currents. The charger connects via a standard 230V AC plug, with an input voltage range of 187–265 VAC, a frequency range of 45–65 Hz, and a maximum output current of 70 A. Charging the battery from 0 to 100% typically requires no more than 12.5 hours.

Warning: To prevent battery degradation or damage, charging must not be performed at ambient temperatures below 0°C or above 45°C. Always ensure the robot is located in a suitable environment before initiating a charging cycle.

Battery operation is fully automated; no user interaction is required under normal conditions. System status, including the state of charge and any fault conditions, is continuously monitored and displayed on the robot's interface screen.

Warning: If a fault is detected in the battery system, the robot will be disabled and cannot be operated. Operation must only resume once the issue has been properly diagnosed and resolved by qualified operator or by the developers.

2.4.6 Hydraulic system

The robot is equipped with a hydraulic system for driving the soil sampler. The hydraulic system consists of a hydraulic tank (70 l), with suction filter (90 µm) and return filter (10 µm), a hydraulic pump (10.2 cc) powered by an electric motor (6 kW), multiple hydraulic valves (, a pressure sensor and a manometer. The hydraulic valves are coupled to quick-attach couplings. Care must be taken to connect the soil sampler only to the 4/2 valve in the correct flow direction.

The hydraulic system must be serviced after 50 hours after the first commissioning, after the initial 300 hours and after every 500 hours thereafter. Servicing means replacing the oil and the filters (both suction and return filter). Remove the old oil using the oil drain plug on the bottom of the hydraulic reservoir. Inspect the reservoir for any signs of contamination, debris or water, and fill the reservoir only with clean hydraulic oil of the correct type (HVLP 46), at the correct volume (50 l). Regularly check the oil level of the hydraulic tank and ensure there is no trace of leaking oil. Also check the in-built breather filters on the tank regularly. When serviced, reset the respective counter in the dashboard of the operation screen.

2.4.7 Preventive soil sampler maintenance

The upper insertion end of the gauge auger, the slotted hole, and the locking bolt should be well greased. There is a grease nipple on the hydraulic hammer for weekly lubrication without disassembly.

The main wear parts are the locking bolts for the gauge auger, the gauge auger, the scraper, and the broaching hub. In this manual, we describe the main maintenance instructions. For more detailed maintenance instructions, we refer to the user manual of the MP4.100 soil sampler.

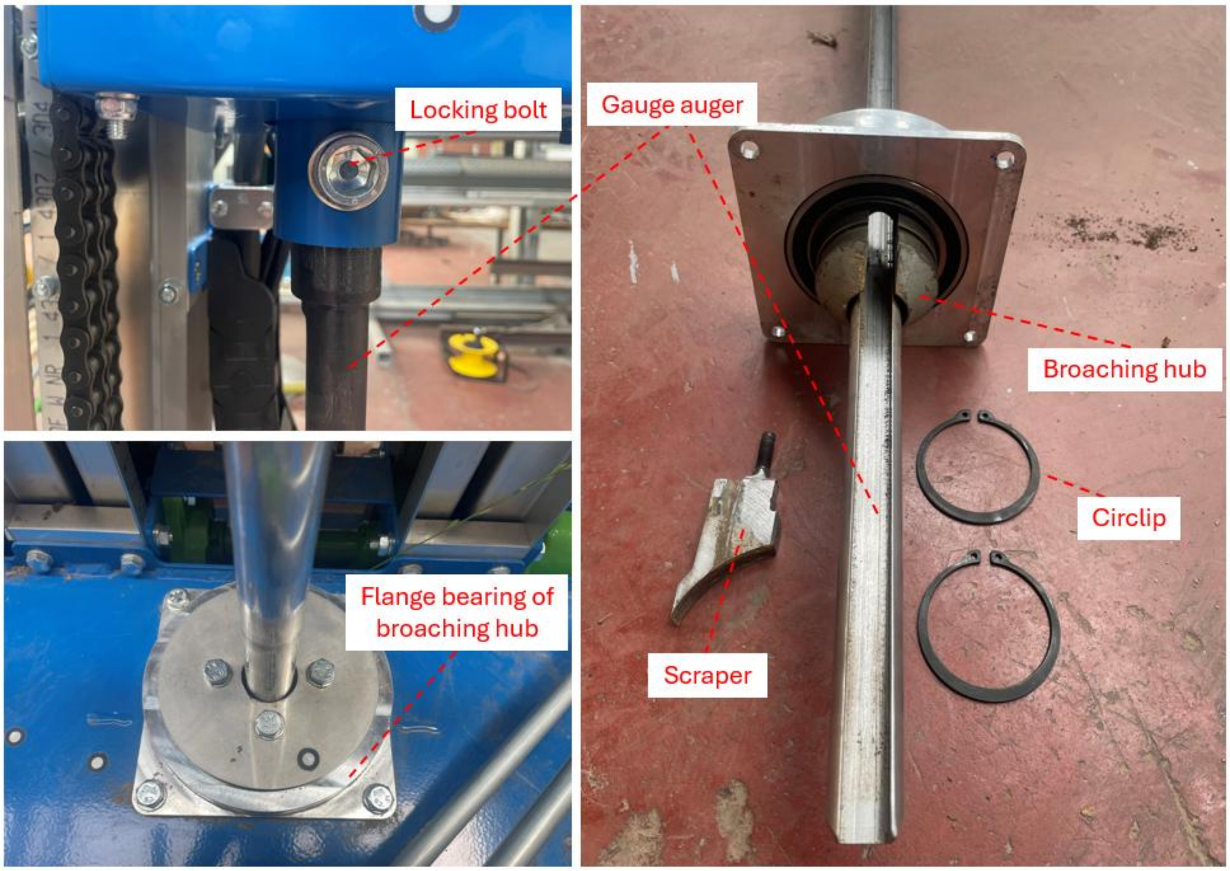
Warning: All worn or damaged parts must be replaced to ensure safe and accurate soil sampling. Before maintenance, move the soil sampler to the transport position and press the **emergency stop button**.

According to the manufacturer, for every one gauge auger that wears out, two scrapers and one locking bolt typically need to be replaced. However, they mention that the rate of wear strongly depends on the soil conditions, especially soil type and soil moisture content.

2.4.7.1 Dismantling

To dismantle the wearing parts, unscrew the locking bolt of the gauge auger, remove the screws from the flange bearing of the broaching hub, tilt the head of the gauge auger, and pull it upwards past the carriage and out of the collection magazine. Finally, pull the complete clearing unit from the gauge auger.

To remove the scraper, remove the lock nut and the two circlips, then pull the scraper downwards out of the hub. The broaching hub is dismantled by removing the circlip and pressing the hub out of the bearing.



2.4.7.2 Reassembling

To reassemble the broaching hub, clean and grease the bearing seat of the flange bearing and of the new broaching hub. Then press the broaching hub into the new bearing. Insert the new scraper into the broaching hub and screw a new M8 lock nut onto the threaded spindle of the scraper.

Warning: There must be a clearance of 2 mm between the nut and the top of the broaching hub so that the broaching tool can oscillate freely. This compensates for wear and ensures that the boring bar groove is cleared cleanly.

Push the clearing unit approximately 20 cm onto the gauge auger. Fit the first and second circlip for the scraper and grease well. Grease the gauge auger head, including the slotted hole, locking bolt, and impact tappet. Insert the gauge auger with the clearing unit from above and secure it with the locking bolt and the M16 self-locking nut. Finally, mount the bearing seat of the broaching hub onto the magazine using four screws.

2.4.7.3 Chain maintenance

The lifting carriage is moved up and down by a duplex chain, running over a sprocket shaft at the top and over the drive shaft at the bottom. The sprocket shaft is used to tension the chain. To do this, open the cover on the head housing, loosen (but do not remove) the two screws and nuts on the flange bearings. The two clamping screws are located on the head housing and can be tightened. This should be done evenly; the manufacturer recommends alternating ¼-turns. The chain is sufficiently tensioned when the two strands can be pressed together with moderate force at approximately the midpoint between the drive shaft and the tensioning shaft. Finally, re-tighten the nuts and bolts on the bearings and refit the cover.

Warning: Before performing maintenance on the chain, raise the tower, secure it with **fall protection**, and press the **emergency stop**. The chain should be treated with chain lubricant at least once a month and should always be lubricated before storing the machine for a longer period.

2.5 Transportation

For transportation on public roads, the robot must be transported on a braked tilt-bed or machine transporter type trailer (typically 12° inclination angle). The trailer must comply with relevant local road transport legislation.

Before transport: position the robot centrally on the trailer, both laterally and longitudinally, to ensure the load is evenly distributed. Proper weight distribution is essential for safe and stable transport. Shut the robot down completely (see 2.3.7). This will automatically engage the brakes, ensuring the robot remains stationary during transport. Secure the robot using appropriate and approved tie-down straps, fixed to designated anchor points on both the robot (4x) and the trailer. The robot must be firmly lashed according to local regulations to prevent any movement.

Additional guidelines:

- Ensure the trailer or tilt-bed is parked on level ground during loading and unloading.
- Use loading ramps suitable for the robot’s ground clearance and weight.
- Verify that the transport vehicle is rated for the total weight of the robot and equipment.

2.6 Storage

When not in use, the robot should be stored in a covered trailer, container, barn, garage, or equivalent where the robot can stand in shelter from rain, snow, wind, or other negative impacts from the environment. Before storage, make sure the robot, soil sampler and penetrometer are cleaned.

3 SQAT continuous mapping robot

3.1 General information

3.1.1 Manufacturer contact information

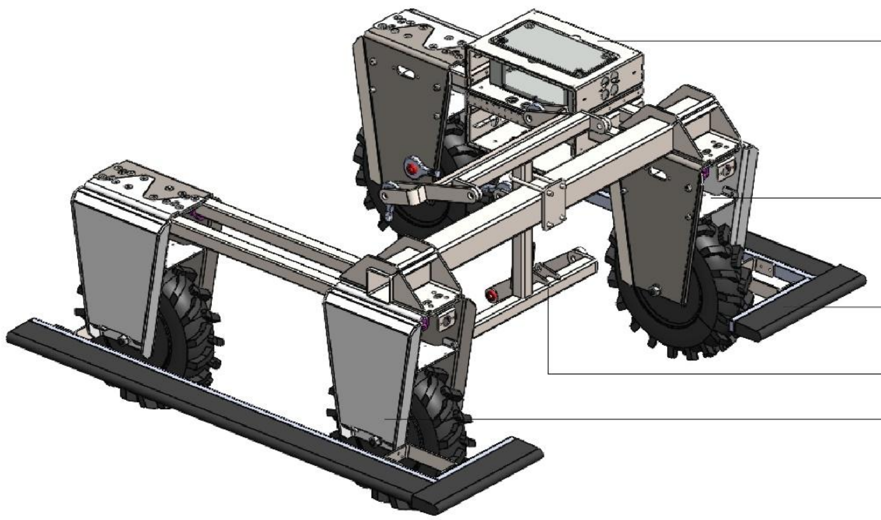
General contact info:
Exobotic Technologies
Steenweg 146A, 9810 Nazareth-De Pinte
Mail: info@exobotic.be

For urgent support:
Jorre Deschuyteneer, R&D Engineer @ Exobotic Technologies
mail: jorre@exobotic.be
tel: 0474 12 30 57

3.1.2 Purpose, structure, and function of the robot

The robot was developed as a lightweight tool carrier, specifically for carrying the ATB hyperspectral sensor tool. In the SQAT project, the robot cannot be used for any other purposes without the explicit written consent of Exobotic.

Amiga is a modular electric utility vehicle designed to tackle time-consuming, mid-load manual tasks with efficiency and precision. It can haul up to 360 kg, tow up to 190 kg, and lift up to 125 kg with a Cat 0 hitch. The base weight of 180 kg minimizes ground compaction. Few standardized parts and an open structure allow for easy diagnosis and quick repairs. Adapt the frame length and width by interchanging connection tubes of different lengths. The platform is easy to maneuver in tight spaces in the field, orchards, tree nurseries or greenhouses, between rows or above crops through a 4×4 all-electric skid-steer platform, powered by 250-watt sealed brushless DC geared motors. Pendant control is used for easy manual speed and steering control, including turning in place. Amiga can run for up to 8 hours on a single charge (no payload) with inexpensive, swappable batteries. The batteries are charged with a standard 5 A charger.



3.1.3 Technical specifications

Manufacturer	Exobotic Technologies
Dimensions	
Empty weight	174 kg
Track width	1000 to 3000 mm center to center
Length	1435 mm
Height	1384 mm
Operational specifications	
Motor power	4x 250W (Driving + steering)
Wheel diameter	430 mm
Tire pressure (max rating)	1,8 bar
Software system	Proprietary
Nominal forward velocity	1 m/s
Maximum forward velocity	2,5 m/s

Nominal traction force (at 1 m/s)	925 N (asphalt) 845 N (compacted soil) 665 N (loose, ploughed soil)
Maximum traction force (at 0,5 m/s)	1915 N (asphalt) 1795 N (compacted soil) 1665 N (loose, ploughed soil)
Battery	
Battery capacity	up to 4x 655 Wh
Battery chemistry	$LiMn_2O_4$
Nominal battery voltage	44 V
Maximum charge current (external charger)	5 A

3.2 Safety instructions

This robot platform is a prototype and is currently in the research and development phase. It consists of multiple off-the-shelf components. However, as a compound machine, it is yet to undergo CE conformity assessment and therefore does not currently have CE certification.

The robot must be operated with caution and under continuous supervision to ensure that all safety measures are correctly implemented and adhered to during use.

The robot is equipped with several safety features to protect users and bystanders from dangerous situations during manual and autonomous use of the machine.

Warning:

- The robot must be used exclusively for its intended purpose and cannot be adapted or rebuilt. Otherwise, manufacturer conformity will expire, and all liability then lies with the operator/owner of the machine.
- The robot must always be powered off before performing maintenance tasks.
- Only trained operators who have followed official training can operate, maintain, and/or repair the machine.
- All safety-related parts and warning notices attached to the machine have not been removed or tampered with.

3.2.1 Safety devices and their function

1. **Emergency stop button**
   The emergency stop button, located above the robot's control panel next to the operation screen, immediately cuts power to the wheel motors when pressed. While the wheels are equipped with

electrical brakes, these only function when the motors are powered—meaning the robot may still coast slightly due to inertia after an emergency stop.

2. **Pressure-sensitive protection device (safety edge)**
   Safety edges are installed in front of the (front) wheels and along the sides of the vehicle. A safety edge detects a person or part of the body when pressure is applied to the effective actuation area. It is a linear tripping device. Its task is to prevent possible hazardous situations that could affect someone within a danger zone. When a safety edge is actuated, power to the wheel motors is immediately cut.

3. **3D camera sensor with person/object detection**
   This sensor, located at the front of the robot, detects persons and objects on the vehicle's trajectory. Based on the relative speed of the robot to the object, it will first slow down and, if needed, bring the robot to a standstill.

Warning: Currently the robot does not come with a certified safe stop or brake control system. This means that when the emergency circuit is activated, the robot may still coast slightly due to inertia. However, deactivation of the emergency circuit will trigger an automatic reset and bring the vehicle to a standstill. A manual reset will enable operation again. Use extreme caution and, if possible, ensure the area is clear before activating the emergency stop in sloped environments. On slopes, activating (and not deactivating) the emergency circuit may cause the robot to roll freely due to loss of braking.

3.2.2 Machine safety markings

Not yet applied.

3.3 Robot operation

3.3.1 Setup and manual robot operation

3.3.1.1 Manual robot control using attached pendant

Joystick Control

The joystick is an omnidirectional control stick used to manually operate the robot. It allows for intuitive control over:

- Acceleration and Deceleration
- Forward and Reverse Movement
- Turning Left and Right, both in place and during forward or backward moving

Cruise Control (X Button)

- The Cruise (X) button enables cruise control mode, allowing the robot to maintain a steady speed based on the set speed on the control panel.
- To exit cruise control and bring the robot to a gradual stop, press the Cruise (X) button again.

Brake (O Button)

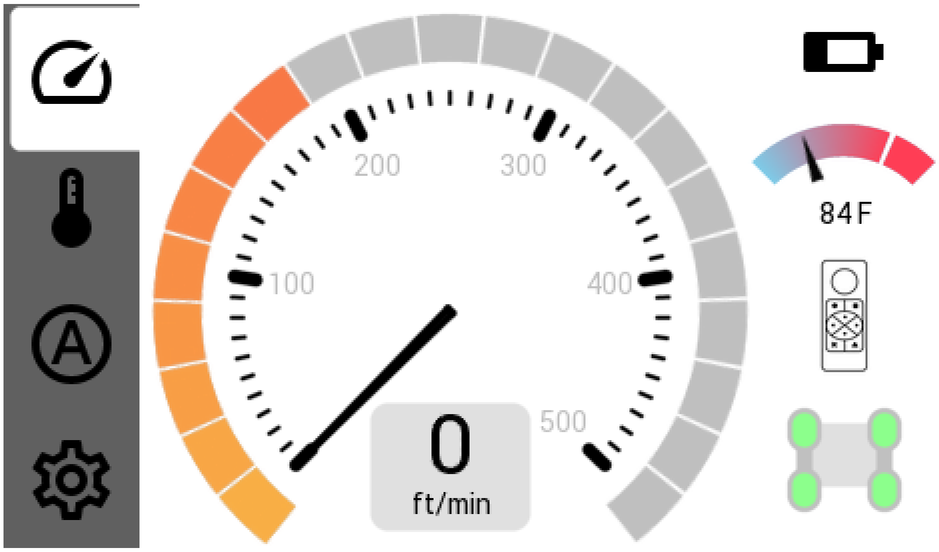
- The Brake (O) button immediately halts all motor activity and cancels cruise control if active. Use this button to quickly stop the robot when needed.

3.3.1.2 Dashboard – Start screen

The **Start Screen** is the first page displayed when the robot is powered on. From this screen, you can select your preferred display language—**English**, **Spanish**, or **French**.

Once a language is selected, press the **START** button to proceed to the **Home Screen**.

3.3.1.3 Dashboard – Home screen

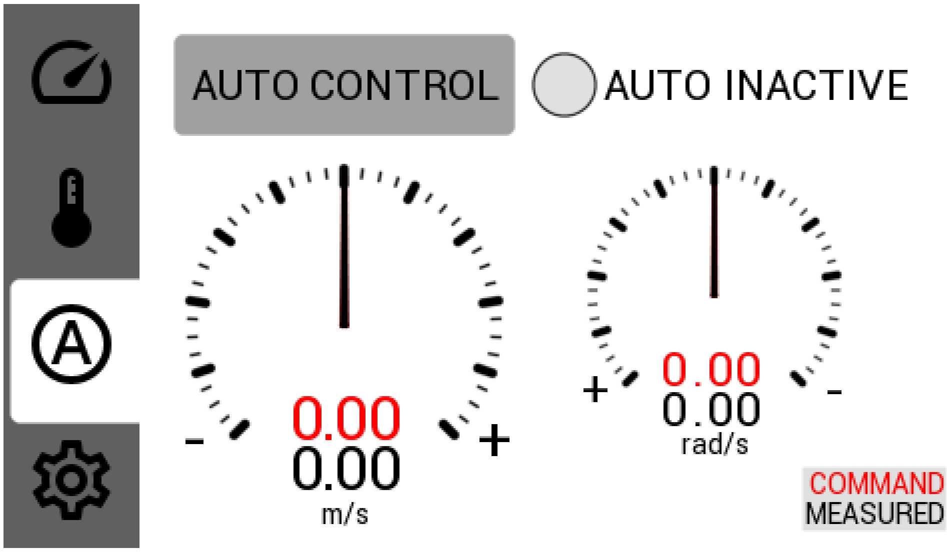


The **Home Screen** is the main interface of the dashboard.

- At the **center**, you'll find the **speedometer**, which displays the robot's current speed. You can switch between **metric** and **imperial** units and adjust the target travel speed from this section.
- On the **right side**, several status icons provide real-time information, including:
  - **Battery Level**
  - **Average Motor Temperature**
  - **Connection Status** with the pendant
  - **Motor Health Preview** for each individual motor

To return to the Home Screen at any time, press the **icon in the upper-left corner** of the dashboard.

3.3.2 Autonomous robot operation



To enable autonomous robot operation, it first needs to be enabled in the Auto Control Screen on the integrated display. Press the auto control button for autonomous control to be activated.

All autonomous behavior is managed through the **Exobotic web platform**.

3.3.2.1 Exobotic Web Platform

As of 28-07-2025, the Exobotic web platform is still in active development and subject to a lot of changes, as such it is not included in this manual.

3.3.3 Remote monitoring

As of 28-07-2025, the remote monitoring and teleoperation tools are still in active development and subject to a lot of changes, as such it is not included in this manual.

3.3.4 Shut down

1. **Deactivate Auto Mode:**
   If the robot is operating in Auto Mode, disable it via the dashboard.
2. **Ensure Safe Positioning:**
   Bring the robot to a complete stop on a flat, level surface.
   Do not shut down on a slope, as disabling the motors may allow the robot to roll due to inertia or gravity.

3. **Turn Off Batteries**
   Turn all battery key switches to the OFF position. Ensure all keys are set to the same state.

4. **Disconnect Power (Optional)**
If the robot will not be used for an extended period, disconnect the IEC C14 power connectors and remove the batteries following the standard Battery Removal procedure.

3.4 Maintenance

3.4.1 Battery replacement and charging

Amiga is powered by up to four batteries, each one located above a wheel. Each battery contains a key switch on its side. The switch serves a dual purpose, locking the battery on its respective drawer-type mount and enabling power for the robot. When batteries are connected to your Amiga, they either need to have ALL keys in the "ON" position or ALL keys in the "OFF" position. When in doubt, follow the standard procedures:

Powering the Amiga ON

1. Slide the battery in using the mounting platform and the grooves located under the battery.
2. Insert the key and turn it to the OFF position.
3. Connect the IEC C14 power connector to the back of the battery.
4. Repeat the first three steps for the other batteries
5. Turn batteries ON, powering the Amiga.

Powering the Amiga OFF

1. Turn all batteries' keys to OFF position, and all systems will power off.
2. Disconnect the IEC C14 power connector from the back of each battery.
3. Turn the key switch to the UNLOCK position and remove the keys.
4. Pull the batteries of the robot using the handle and carefully place it on the ground.
5. Repeat the last three steps to remove the other batteries.
6. Move the batteries to a safe location, away from flammable materials and other structures.

When connecting batteries in parallel (standard setup), it is required that all batteries have their voltages matched to avoid one discharging itself into the other one at a higher current rate than it is rated for. The most effective way to achieve this is by ensuring both batteries are fully charged before connecting them to your Amiga and keeping them both ON during all operational time. Another simpler way to do this is to charge the batteries through the auxiliary plugs on the 48V bus. Note that all batteries should be ON while charging.

Warning

Operating the Amiga with batteries at different charge levels/voltages can lead to high currents moving from one battery to the other, which can cause permanent damage to the internal cells. With repeated charge/discharge cycles in these conditions, these damages can build up and increase the risk of a battery failure. Battery failures are potentially dangerous events that can cause fires that spread fast through other components of your Amiga and nearby structure. To minimize this risk, DO NOT charge or discharge (operate) batteries with different charge levels/voltages connected.

Fuses

To protect all circuits in the Amiga, all batteries are equipped with a fuse located on its side close to the power output connector. The fuse must be of a 30 Amp, slow blow, ceramic type. Remove it using a phillips screwdriver.

Charging the Amiga

To charge your batteries, either:

i. Remove them from the robot, lift the handle and connect the charger. You will notice the LED in your charging brick will turn RED while the battery is charging and GREEN when done.
ii. Keep all installed batteries switched ON in the robot. Connect the charger to one of the auxiliary ports on the 48V bus. You will notice the LED in your charging brick will turn RED while the battery is charging and GREEN when done.

Warning

Battery charging involves high electric currents and, as any equipment operating at this capacity, has an electrical risk associated with. When charging your batteries make sure the chargers, cables, and batteries are in good condition. For additional safety, charge in an open area, away from flammable materials, structures, and ideally on a concrete floor. This setup minimizes the risk of fire spreading in the unlikely event of an incident.

3.4.2 Preventive robot maintenance

Recommended maintenance tasks after each use include:

- Inspect and clean machine surfaces and components
- Inspect electrical connections for damage
- Inspect for loose connection elements (bolts, pins)
- Test emergency stop buttons and safety edges
- Ensure all moving parts operate without unusual noise
- Check tire condition and pressure for proper inflation
- Verify battery charge level and recharge if necessary
- Ensure the lift mechanism operates smoothly and all hinge points are lubricated sufficiently using an all-purpose lithium-based grease.

3.5 Transportation

Shipping the robot for export should always be done in an export certified ISPM-15 pallet crate of 120 x 100 x 114 cm. The crate material (typically plywood) should be incompressible and moisture resistant. The robot should be strapped firmly to the pallet using the designated anchoring points (4x) on the robot frame.

National transport of the robot (deployment purposes) can be done with a standard car trailer or machine transporter with a bed size 150 x 200 cm or larger. The robot should be strapped firmly to the bed using the designated anchoring points (4x) on the robot frame.

3.6 Storage

When not in use, the robot should be stored in a covered trailer, container, barn, garage, or equivalent where the robot can stand in shelter from rain, snow, wind, or other negative impacts from the environment.

4 SQAT lightweight soil sampling robot

4.1 General information

The ANYmal from Anybotics serves as the carrier platform, providing mobility and autonomy in challenging environments. The primary innovation in this system is the lightweight soil sampler, designed to efficiently drill small holes in various soils. This manual describes the operation and integration of the lightweight soil sampling platform module designed to be mounted on a robotic carrier platform. While safety and operational behavior of the robot are addressed as far as necessary for platform integration, detailed robot specifications, maintenance procedures, and safety guidelines are documented in the official ANYmal from Anybotics user manual, which is available to authorized users only.

4.1.1 Manufacturer contact information

Mobile robot:
Anybotics
Hagenholzstrasse 83a,
8050 Zürich, Switzerland

Lightweight soil sampler:
OST - Eastern Switzerland University of Applied Sciences
ISF - Institute for Intelligent Systems and Smart Farming
Tänikon 5, 8356 Ettenhausen, Switzerland
isf@ost.ch

4.1.2 Purpose, structure, and function of the robot

The lightweight soil sampler is an innovative tool designed for efficient soil sampling in precision agriculture, particularly within the SQAT project. As depicted in Figure 4.1, this compact device integrates two primary systems:

Mobile Carrier Platform: The lightweight soil sampler is designed to be mounted on a variety of mobile carrier platforms, depending on the application and operating environment. These platforms may range from autonomous ground vehicles to manually operated systems. For advanced use cases, the sampler can be integrated with legged robotic systems—such as quadrupedal robots—which offer enhanced mobility across uneven or soft terrain. The platform's role is to provide stable transport, positioning, and power to the soil sampler during operation. Specific capabilities such as suspension, autonomy, or safety features depend on the chosen carrier and are not part of the soil sampler system itself.

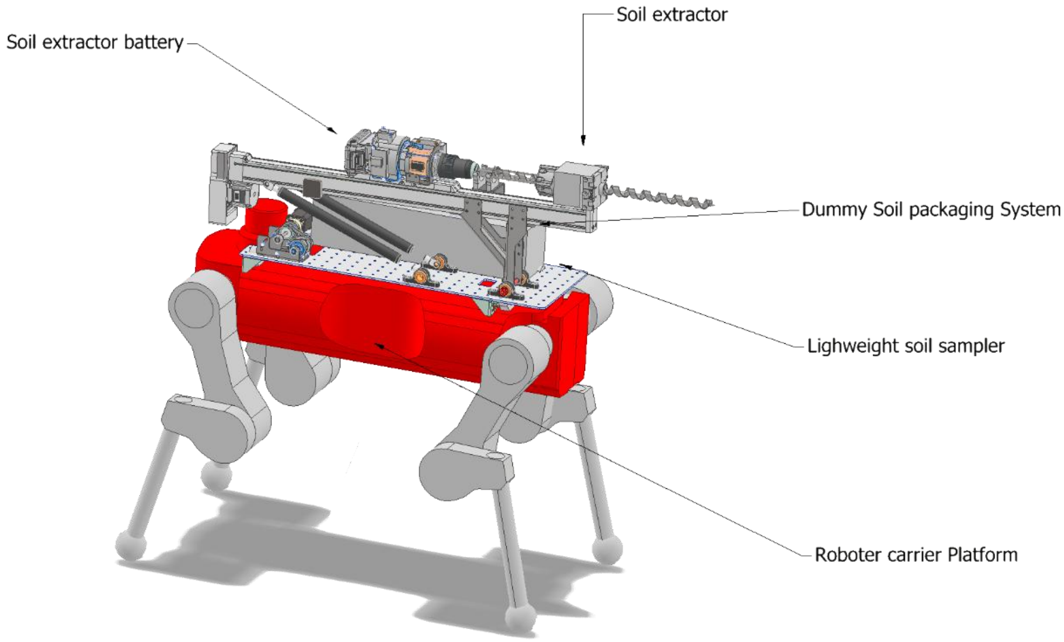


Figure 4.1 2 Carrier platform with mounted lightweight soil sampler

Lightweight Soil Sampler: The heart of the lightweight soil sampler is its soil sampling unit, engineered for precision and reliability. This unit employs a spiral auger mechanism that gently penetrates the soil to collect samples up to 500 mm deep. The auger is driven by an electric motor. The sampling process is fully customizable, allowing users to adjust parameters such as depth, speed, and sample size.

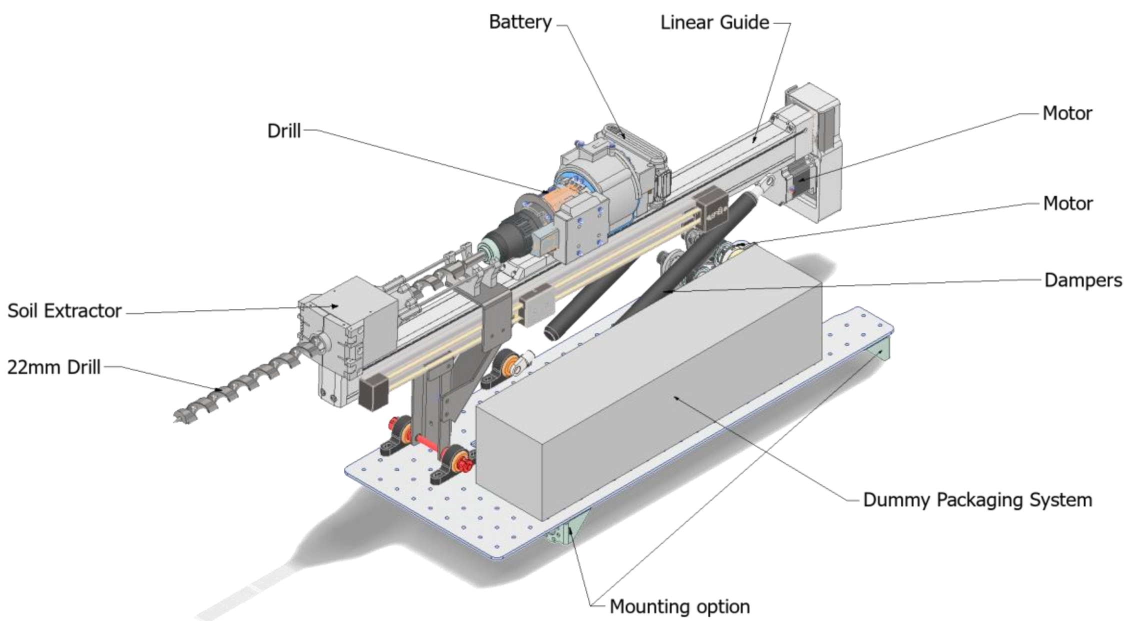


Figure 4.2 3 Lightweight soil sampler

This lightweight soil sampler (Figure 4.2 3) is designed for use by trained professionals and adheres to all relevant safety and regulatory standards applicable at the time of manufacture. Users are advised to consult local regulations and guidelines prior to operation to ensure compliance and safe usage.

Designed with versatility in mind, the lightweight soil sampler is a modular system capable of being mounted on a wide range of mobile carrier platforms. Its compact footprint and standardized mechanical interface make it suitable for integration with legged robots, wheeled rovers, tracked vehicles, or even simple manual platforms such as a wheelbarrow. This flexibility allows the system to adapt to diverse operational environments, from autonomous field robotics to low-tech, manually operated setups, without compromising sampling precision or performance.

4.1.3 Technical specifications

Carrier platform

Manufacturer	ANYbotics
Type	ANYmal
Empty weight	50 kg
Length	891 mm
Width	651 mm
Height	872 mm (440 mm lying on ground)
Payload capability	~15 kg
Max speed	1.8 km/h

Lightweight soil sampler

Manufacturer	ISF
Length	891 mm
Width	651 mm
Height	872 mm
Weight	~14 kg

Interface	Serial / USB / Ethernet
Data Connection	Ethernet, ROS2

4.2 Safety instructions

Only trained personnel who have attended official training sessions and thoroughly reviewed this manual, its safety are permitted to operate the system. It must be used with care and under constant supervision to ensure all safety protocols are followed.

The robot includes several safety features designed to protect users and bystanders during both manual and autonomous operations. It should only be used for its intended purpose and must not be altered without the manufacturer's consent. Always power off the robot before conducting any maintenance. Usage is restricted to private property, and transportation on public roads requires a compliant trailer.

Only those who have completed the official training are authorized to operate, maintain, or repair the machine. Maintenance and repairs should be conducted in direct consultation with the developers. All safety components and warning labels must remain intact and unaltered.

4.2.1 Safety devices and their function

The soil sampler includes safety mechanisms designed to ensure safe operation when integrated into a complete robotic system.

1. **Emergency Stop Interface:**
   The soil sampler can be externally stopped via a digital signal or network command. It is expected to be integrated with the emergency stop system of the host platform. Upon receiving a stop command, all actuators are halted, and motor power is cut immediately.

2. **System Dependency:**
   The soil sampler requires a fully initialized and operational host platform to function safely. If the platform is not correctly booted or is in an unknown state, the soil sampler must remain inactive. This dependency ensures the sampler cannot operate without system-level coordination.

3. **Operational Readiness Checks:**
   The sampler performs internal health checks at startup and will not begin sampling unless key parameters (e.g., power, communication, sensor feedback) are within safe limits.

Note: The safety mechanisms of the host platform (e.g., mobility systems, obstacle detection, platform-level emergency stop) are outside the scope of this manual. Refer to the platform manufacturer's documentation for details on those systems.

4.2.2 Machine safety markings

As of the current development stage, the soil sampler does not yet include finalized safety markings or warning labels. The system is still undergoing testing and validation, and all applicable safety labeling in accordance with standard machinery directives will be added prior to release.

Planned safety markings include:

- Warning labels near moving components such as the auger housing
- Voltage hazard symbols near power input and connectors
- Pinch-point warnings at mechanical interfaces
- An emergency stop interface label (if integrated into the final system)

Note: Until all safety labels are applied, the system must only be operated by qualified personnel familiar with its hazards and functions. Use in field or production environments is not permitted at this stage.

Final labeling and documentation will be updated to reflect the certified system configuration once development is complete.

4.2.3 Machine operation risks

When the soil sampler is not used in accordance with the safety instructions and operational constraints, the user may:

- Cause unintentional actuation of the auger mechanism
- Damage the host platform by exceeding mechanical or electrical interface limits
- Compromise the safety of surrounding personnel or equipment due to unexpected motion
- Cause inaccurate or invalid soil sampling results
- Violate host platform safety constraints (e.g., overload, timing conflicts)
- Lose control of the robot (indirectly, via interface misuse or improper integration)

Proper training, validated system integration, and thorough understanding of interface behavior are required to mitigate these risks.

4.3 Robot operation

The soil sampler is dependent on a fully initialized and functional robotic platform for operation. This section outlines the high-level modes of use when integrated into such a system. Specific details of robot navigation, localization, or autonomy are outside the scope of this manual and must be referenced in the host platform documentation.

4.3.1 Setup and manual robot operation

In manually operated configurations, the robot can be positioned by the operator near a desired sampling location. Once positioned and stable, the soil sampler may be armed or triggered via remote command or host system interface. The operator must ensure that:

- The sampler is not obstructed
- The terrain is stable and clear
- The robot remains stationary during sampling

Integration with the host system must ensure that motion is locked or disabled while sampling is in progress.

4.3.2 Autonomous robot operation

In autonomous operation mode, the soil sampler defines target sampling locations based on integrated GPS RTK data. The sampler communicates the desired coordinates to the host platform via the ROS 2 interface.

The host platform is responsible for executing locomotion and navigating to the requested GPS position. Once the host platform confirms arrival and stability, the soil sampler initiates the sampling process. Throughout this sequence, the soil sampler monitors positional accuracy and environmental conditions to ensure proper sampling.

⚠️ Note:

The host platform does not perform GPS-based navigation independently. All coordinate-based target positions are generated and managed by the soil sampler. Reliable ROS 2 communication between the soil sampler and the host platform is required for proper operation.

The soil sampler remains responsible for task coordination, sampling execution, and reporting of status or errors. The host platform is expected to act solely as a mobility layer under instruction from the soil sampler system.

4.3.3 Soil sampler operation

The soil sampler performs soil extraction using a motor-driven spiral auger. Parameters such as depth, auger speed, and sample volume can be configured via the data interface before operation. Once triggered by the host platform:

1. The auger begins rotation and lowers to the target depth
2. Soil is collected into the integrated collection chamber
3. The auger retracts and the system signals completion

Real-time status, fault detection, and telemetry are published via the communication interface. Operators must ensure the sampler is clean and unobstructed before each cycle.

4.3.4 Remote monitoring

The soil sampler supports remote monitoring through its digital interface. System status, sampling progress, fault codes, and sensor feedback (e.g., current draw, temperature, positional data) can be accessed by the host platform. Remote access must be implemented by the system integrator using the provided communication protocol (e.g. ROS2).

4.3.5 Shut down

To safely shut down the soil sampler:

1. Ensure the sampler is idle and no sampling process is active
2. Send a software shutdown command via the host interface
3. Remove power only after safe disarm confirmation is received

Shutting down the sampler during active operation may damage internal mechanisms or cause data loss.

4.4 Maintenance

Regular maintenance is required to ensure safe and reliable operation of the soil sampler. The following sections cover routine maintenance of the system and any user-serviceable elements.

4.4.1 Battery replacement and charging

The soil sampler is powered by a compact, user-replaceable lithium-ion battery located in the upper housing. This battery is used to supply power to the drilling mechanism independently of the host platform.

Important:

Only use batteries and chargers that are approved by the manufacturer or specified for this system. Use of incompatible batteries may result in malfunction or safety hazards.

To replace or recharge the battery:

1. Ensure the soil sampler is switched off and disconnected from the host system.
2. Release the battery lock mechanism and remove the depleted battery.
3. Charge the battery using a compatible charger, following the charger manufacturer's instructions.
4. Reinsert the fully charged battery until it clicks into place.

Regularly inspect the battery for damage, excessive wear, or reduced performance. Replace as necessary. Do not expose the battery to moisture, excessive heat, or mechanical shocks.

4.4.2 Preventive robot maintenance

Preventive maintenance for the host platform (e.g., battery health, mobility system, sensors) is not covered in this manual. Refer to the platform manufacturer’s documentation for required maintenance intervals, procedures, and replacement parts.

4.4.3 Preventive soil sampler maintenance

Recommended maintenance tasks for the soil sampler include:

- **Daily (after use):**
  - Clean auger shaft and housing to remove soil residue
  - Inspect for wear, damage, or loose fasteners
- **Weekly:**
  - Check electrical connectors for corrosion or dirt
  - Verify torque on mounting hardware
  - Inspect motor and gearbox for abnormal noise or vibration
- **Monthly:**
  - Perform full diagnostic cycle

Failure to maintain the soil sampler may lead to inaccurate sampling or mechanical failure.

4.5 Transportation

The soil sampler must be transported in protective packaging that secures all moving parts and protects against mechanical shocks. The use of a custom foam-lined case is strongly recommended to avoid internal damage.

4.6 Storage

When not in use, the robot and soil sampler should be stored in a car, covered trailer, container, barn, garage, or equivalent where the robot can stand in shelter from rain, snow, wind, or other negative impacts from the environment.

5 Conclusion

This deliverable bundles the three user manuals for the robots developed for the SQAT project. The respective manuals apply exclusively to the respective robots. The manuals intend to inform users and enable them to safely and efficiently operate and service the robots. It should be noted that each manual reflects the current state of the robot systems at the time of writing. Since the robots are still under active development within the project, both hardware and software components may undergo significant changes, requiring adaptations in the user manuals. Since the developed robots are prototypes, intended solely for research purposes, the robots do not bear CE marking, however despite this, all developments are carried out in alignment with relevant EU directives and regulations, using harmonized standards and completing a risk analysis.

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