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Specifications and KPIs for the two CANOPIES robot prototypes

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Executive Summary

This report describes all the specifications and KPIs that will be defined during the development of the robotic prototypes. Following the development of the robotic prototypes this report will be periodically updated during the project.

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Abbreviations and Acronyms

3D	Three Dimensional
4G	Fourth generation of broadband cellular network technology
5G	Fifth generation of broadband cellular network technology
BEM	Box-Exchange Mechanism
CAN	Controller Area Network
DoF	Degrees of Freedom
EtherCAT	Ethernet-based fieldbus system.
FOV	Field Of View
GigE	Gigabit Ethernet
GNSS	Global Navigation Satellite System
HRI	Human Robot Interaction
IMU	Inertial Measurement Unit
ISO	Reference to standards from the International Organization for Standardization
KPI	Key Performance Indicator
LED	Light Emitting Diode
LIDAR	LIght Detection And Ranging
LTE	Long-Term Evolution communication standard
NTRIP	Networked Transport of RTCM via Internet Protocol
NUC	Next Unit of Computing
OS	Operating System
PPS	Pulse Per Second
RGB	Red Green Blue (referring to the camera channels)
RGB-D	Red Green Blue + Depth (referring to the camera channels)
ROS	Robot Operating System
RS-485	Serial communication protocol
RTCM	Radio Technical Commission for Maritime Services (GNSS communication protocol)
RTK	Real Time Kinematic
SEE	Serial Elastic Elements
SLAM	Simultaneous Localization And Mapping
UHF	Ultra High Frequency
USB	Universal Serial Bus
WiFi	Wireless network communication protocols
WP	Work Package

1. Introduction

"Specifications and KPIs for the two CANOPIES robot prototypes" is a deliverable for WP2 – describing the requirements and specification of the developed robot prototypes and all its comprising subsystems, from physical aspects of the robots' design to the individual software specifications. From the specifications, we also extract some KPIs which will provide us with the possibility to measure the performance of our systems and revisiting our design decisions in case of problems experienced during the experimental validation.

In CANOPIES, we will explore the potentials of robotic research on a collaborative human-robot paradigm with the addition of coordinated multi-robot teams for the agronomic task of harvesting table grapes and pruning the vines. To that end, the consortium is expected to develop two prototype robotic solutions with different capabilities. The first prototype, named the farming robot, is going to be used for pruning and gathering the grapes, while the other one, named logistic robot, will service the farming robot by transferring boxes full of grapes in a predefined area in the field. Both envisioned robot prototypes can be found in Figure 1 and 2 respectively.

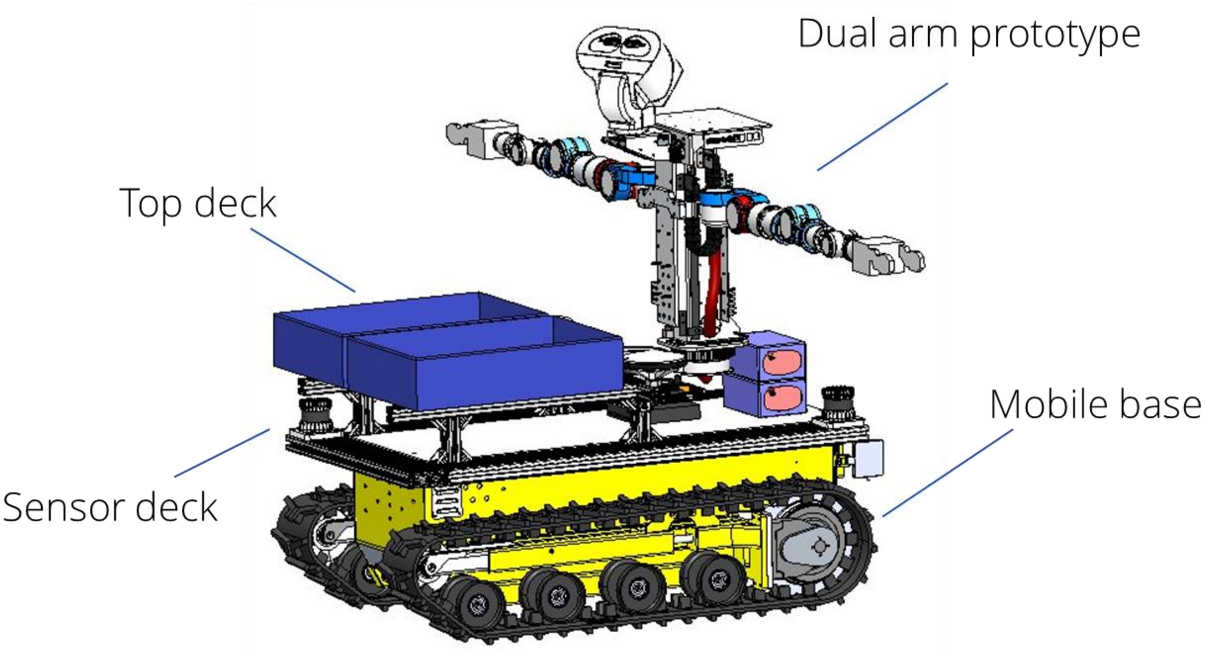


Figure 1:Representation of the farming robot and all its hardware subcomponents.

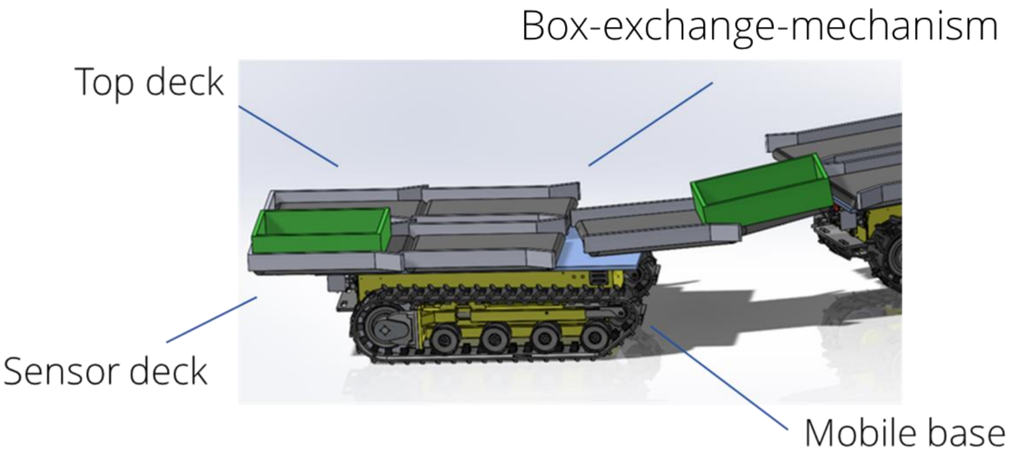


Figure 2: Representation of the logistic robot and all its hardware subcomponents.

In the following sections, we include a description of their comprising subsystems and provide the reasoning behind our development and integration choices. Finally, we define a set of KPIs that represent the foreseen potential of the robotic prototypes at the time that this document is edited.

It must be noted that we consider this document as a live document, which will keep updating until the final demonstrations of this project.

2. Robotic prototype subsystems specifications

2.1. Mobile base platform

The ground vehicle platform is a core component for both the robotic prototypes in this project. Therefore, the platform must comply with the following specifications:

1. Conform with the needs of both prototype robot configurations, the chosen platform should allow for replication between the common parts of the two robot prototypes while conforming with the requirements of the individual subsystems, i.e., the BEM and the dual arm prototype.
2. Enable the robots to achieve their agricultural tasks, for the farming robot to be able to position itself close to vines without losing stability and tipping over while for the logistic robot to be able to carry a heavy mechanism and to line up properly with the farming robot to enable the smooth transfer of empty and full boxes.
3. Cover the academic requirements of the project, to ensure an easy integration and customization while allowing the Consortium partners to focus on the development of the required algorithms and components.

Figure 3: The Alitrak DCT-350P mobile bases in a construction site.

During the drafting of the proposal, the consortium has identified the Alitrak DCT-350P as the mobile platform that covers the above specifications, since it is a market-ready solution that has been tested in harsh environment, such as construction. Therefore, the platform is robust to dust and water while being able to drive in uneven terrain. The DCT350P is also capable of carrying a lot of weight with minimum danger of tipping over. Finally, the platform also has multiple mounting points at its chassis that allow for customization and ease of integration of the envisioned solutions.

2.1.1. Sensorial equipment for navigation

For the purposes of navigation, a set of appropriate sensors were selected. Each sensor selection was based on various specifications such as robustness to environmental conditions, accuracy, and ease of integration. More importantly the sensors should also provide the possibility for sensor fusion, i.e., sensors working in unison and combining their information to achieve the required navigation goals.

The sensorial suite used for navigation can be described in its individual components:

1. RTK-GNSS system

The RTK-GNSS is a localization system that reports a georeferenced location of the robot position with great accuracy. The use of this system is crucial to our case, since RTK-GNSS information are vital for the localization algorithms and the geo-referencing of data coming from other sensors, e.g., image data from agronomic sensors or 3D point cloud data provided by the LIDAR system.

For our system we integrated the Septentrio AsterRx-m3 Pro+[1] in a rover configuration and the Septentrio AsteRx-U[2] in a base station configuration.
The requirements for our rover configuration, which are covered from the selected sensor, can be found here in detail:

1. High accuracy: the selected sensor has a horizontal accuracy of 0,6 cm + 0,5 ppm and a vertical accuracy of 1cm + 1ppm. This high accuracy can provide state-of-the-art localization performance. This covers the needs the academic requirements of this project which were initially to 1,5 cm + 1ppm both for horizontal and vertical accuracy.
2. High update frequency: the selected sensor is capable of providing signals with up to 100Hz frequency. Due to the speed of our platform the provided information is more than sufficient. However, having the possibility to provide accurate data in that frequency could be useful when exploiting our robot system in future tasks and anyway can mitigate low signal strength. Original specification was set to 50 Hz.
3. Protection against interference: the selected sensors is equipped with anti-jamming technology that allows it to combat interference coming from another signal on the robot such as WiFi.
4. Provision of georeferenced heading: the selected sensors can and is equipped with two antennas which provide us with the possibility to use a georeferenced heading. The georeferenced heading is used for replacing the heading provided by the magnetometer in the selected IMU. This specification was deemed necessary since the integrated IMU magnetometers can be susceptible to magnetic interference created by the platform itself.
5. Output of a synchronization signal: the selected sensor is able to provide a 5 ns time synchronization output that will be used for the synchronization of the other navigation sensors, i.e., LIDAR and IMU. This feature is paramount in case of localization, SLAM algorithms and other navigation and agronomic related algorithms that will be developed in the duration of this project. That is because a common reference between the timing of the sensors input will allow us to be sure of the position and time that data were gathered. This allows the time-stamped and georeferenced data that we output to be more accurately positioned.

[1] AsteRx-m3 Pro+ GPS/GNSS receiver | Septentrio
[2] AsteRx-U | Septentrio

6. Ease of integration: the selected sensors can be integrated with the ROS middleware platform. Moreover, the sensor is offered with an enclosed developer kit that makes the solution somewhat dust proof and provides a lot of potential for connectivity and customization.

The requirements for our base station configuration, which are covered from the selected sensor, can be found here in detail:

1. Requirements 1, 3, 5 and 6 from the rover configuration are also important for the base station and are similarly met by its RTK-GNSS sensor.
2. Robust and "turn-key" solution: the Septentrio AsteRx-U sensor comes in a self-contained box which is robust against humidity, dust, shock and vibration. This parameter was very important given that our operational environment will be in an agriculture setting. Once the sensor is set up with the on-board ethernet based interface, it will store all settings to setup a base station. Each time the sensor receives power the setup process starts automatically thus leading to a "turn-key solution" which is robust and will allow required stability during our experimental sessions.
3. Multiple connectivity options: the sensor can transmit and receive information from a variety of wireless communication protocols including UHF radio, WiFi, and 4G LTE. This specification allows us to setup an appropriate communication with the RTK-GNSS rover and fault back to another configuration in the case that we experience problems at a particular site.
4. NTRIP configuration: the sensor can be set as an independent NTRIP server or caster which allows the communication between the base station and rover using LTE technology. This possibility will allow us to setup the base station to a position with strong satellite signal without worrying about the range limitations of UHF and WiFi connectivity.

2. IMU sensors

The IMU sensor is paramount to the localization and navigation capabilities of the robot prototypes. The use of such sensor provides the information about the platform's inertial state, orientation. This sensor's output is also a core part of navigation and localization algorithms that will be developed in this project.

Our choice was the SBG Ellipse-E[3] that covers the requirements for our mobile platform configuration as described here in detail:

1. High accuracy: the sensor can provide accurate measurements of pitch and roll to 0.1 degrees without any additional aids. In our configuration, i.e., fusing RTK-GNSS information, its accuracy can be improved to 0.05 degrees. Moreover, the velocity readings are accurate within 0.03 m/s.
2. High frequency: since our platform is slow moving a high frequency sensor might not be the obvious choice. However, keeping in mind that the terrain where the robot will operate is rough there is a requirement for keeping track of all potential changes to its 3D orientation. Increased benefits of a high frequency sensor will also be observed in the exchange of boxes

[3] https://www.sbg-systems.com/products/ellipse-series/#ellipse-e_miniature-ins

between platforms were information about the orientation and state of the robot is critical. The selected sensor has a maximum fused output (GNNS + IMU) of 200Hz and a 1000 Hz in case that IMU data are required.

3. Low bias and in-run stability: IMU are especially known to drift, i.e., propagating errors about their status and orientation over time. Since the experiments are targeting the operation of the robot for an extended amount of time, we would require as low IMU drift as possible. The SBG Ellipse-E providesbias in-run stability measurements of 14 µg for the accelerometer, 7 degrees/h for the gyroscope and 1.5 mGauss for the magnetometer. The consortium partners consider these values as acceptable for research use.
4. GNSS heading fusion: the selected sensor provides an input for external GNSS and synchronization integration. We take advantage of this feature, providing GNSS and PPS signals from our RTK-GNSS solution. This allows for:
    a. disabling the on-board magnetometer which can create a lot of interference and compromise the IMU stability. Interference was expected and considered from the beginning of the robot concept design since the Alitrak mobile base is made from magnetic metal.
    b. providing the IMU with a more accurate heading and georeferenced position that is used for the internal sensor fusion capabilities.
5. Ease of integration: the sensor can be integrated with the ROS middleware software platform.

3. LIDAR sensors

The LIDAR sensors provide a three-dimensional representation of the world around the robot. This capability is paramount for the navigation and localization capabilities of the robot since it allows for robust, long range and peripheral detection of obstacles while allowing for algorithmically creating maps of the environment and defining fixed anchor points for the detection of state changes in the movement of the robot, i.e., navigation algorithms.

We selected the OS1-64 from Ouster[4] as it fulfils the following requirements set by the consortium:

1. Long range and increased resolution: the OS1-64 is a 64 channel LIDAR that allows for various resolution configuration namely 512 on 20Hz max, 1024 on 20Hz max and 2048 on 10Hz max. This parametrization alongside with the operating range of 120m will allow us to develop algorithms that are focusing either in update speed or localization and mapping accuracy.
2. Synchronization capabilities: the sensors allow for synchronization capabilities from external sources. Once again, this was one of the specifications that was initially planned by the consortium and will allow for all data to be time-synchronized and georeferenced based on the outputs of our RTK-GNSS solution.
3. Ease of integration: this sensor is also integrated with the use of the ROS middleware software.

2.1.2. Sensor placement

Placement of sensors is important since it dictates:

4 https://ouster.com/products/os1-lidar-sensor/

a) how much we can take advantage of the senor's ability to provide us with important information about its surroundings.
b) the amount of interference that the sensor will experience.

In CANOPIES, both robotic prototypes are based on the same mobile platform and equipped with (essentially) the same sensor suite, both to simplify integration and provide a common system that helps us to coordinate research efforts between partners. We devised a sensor placement strategy that achieves the following specifications:

- Sensor installation is identical across robotic platforms: the sensors will be found in the same space regardless of robot prototype version. This guarantees ease of integration, easy replication, and easy troubleshooting, as well as making it less critical that all upgrades are delivered and utilized simultaneously.
- Optimal sensor performance: each respected sensor is describing information from the robot's environment as well as the state of the robot itself. Therefore, any installation of sensors creating occlusions of the FOV and obstruction of signal should be avoided.
- Minimal noise and interference: electromagnetic interference is a very common problem when sensors are in close proximity and can seriously affect a sensor's output. This is obviously detrimental to the research activities relying on this output. Good placement and appropriate shielding of the sensors provides protection from this problem.

We designed a weight-bearing deck that extends over the original top plate of the mobile platform to take advantage of its full length. The deck was constructed not to permit any flexing when it is attached to the robot chassis mounting points supplied by the manufacturer. The deck was edged with an aluminium profile with rails that will enable the CANOPIES partners to easily fix, switch and move sensors and experiment with different sensors and mounting positions. This allows us to investigate different hardware prototypes to serve the academic activities in navigation, human-robot interaction, multi-robot coordination, etc. In the following figures we show the design.

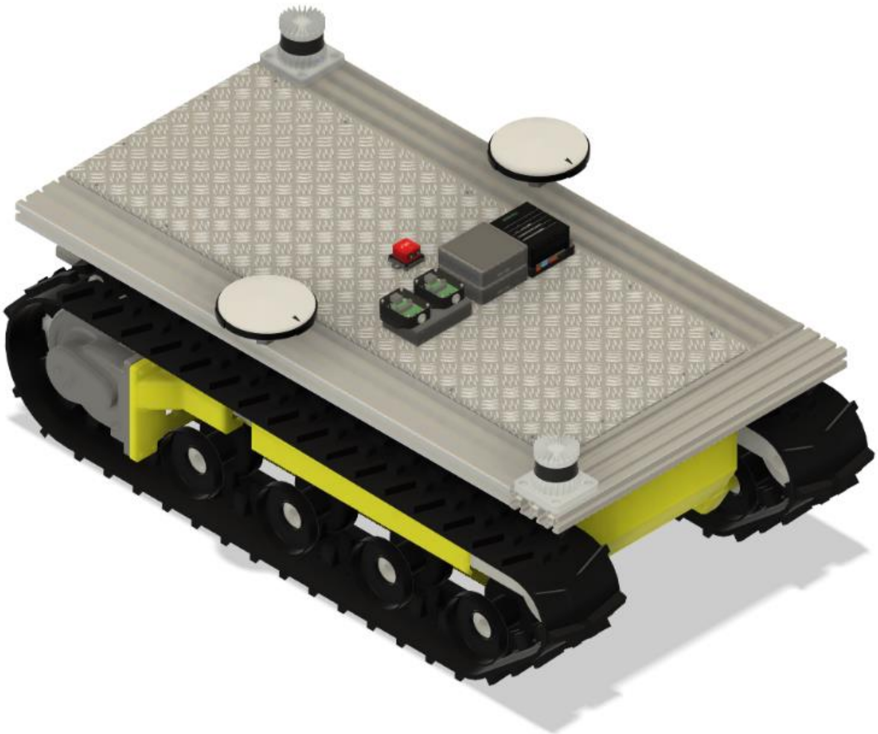


Figure 4: Diagonal view of the mobile base with sensors attached: a LIDAR in two opposite corners, the RTK-GNNS solution and the red IMU in the center denoting the center of rotation. Other fixtures include the green LIDAR interface boxes, the black Nvidia Xavier and a pair of grey Intel NUCs.

Figure 5 The same design seen from the front. Providing a better height perspective of the sensor installation in relation to the rest of the mobile base.

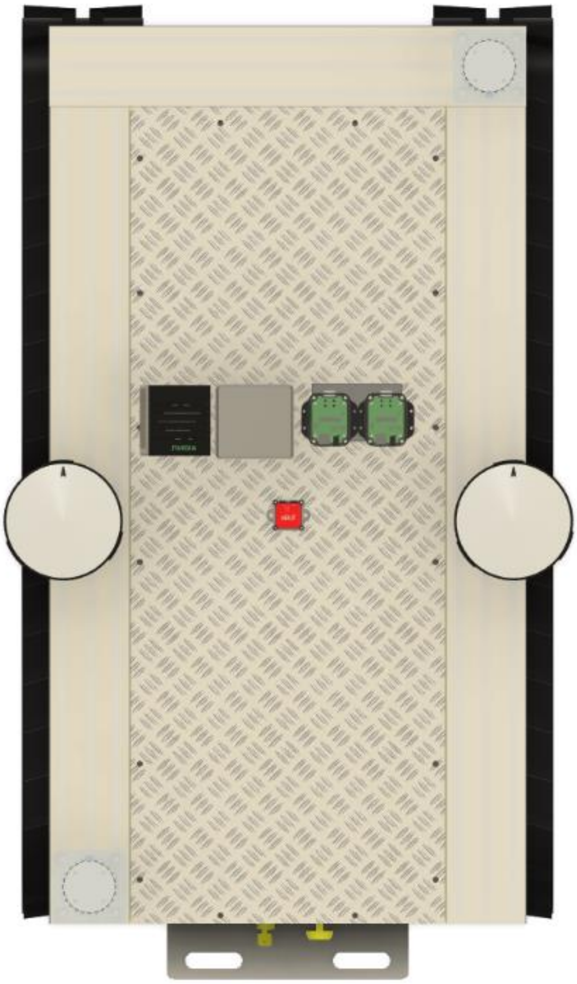


Figure 6: The same design seen from above. Here the footprint of the robot, as well as, the footprint of the sensors on top of the platform can be observed.

Figure 7: The same design seen from the side. Complementing the information of the previous figures.

The LIDAR sensors are placed in a diagonal configuration where they achieve a full 360-degree coverage as shown. This configuration allows each sensor to cover 270 degrees despite the occlusions from other sensors and equipment, and the dual arm robot or box mechanism placed on the base.

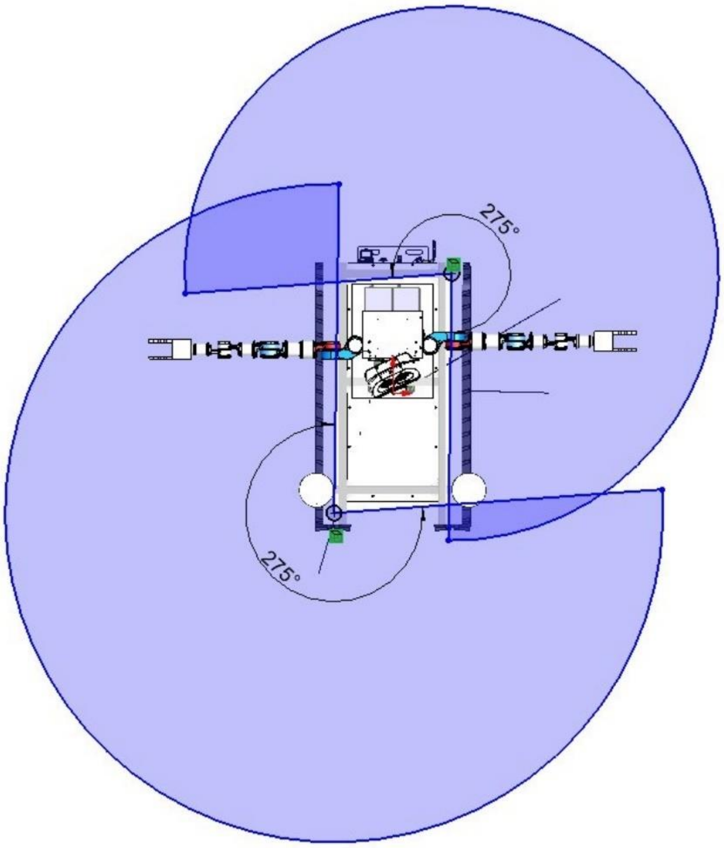


Figure 8: Diagram of the field of view of the LIDAR sensor configuration for the farming robot. The logistic robot has the same LIDAR sensor installation.

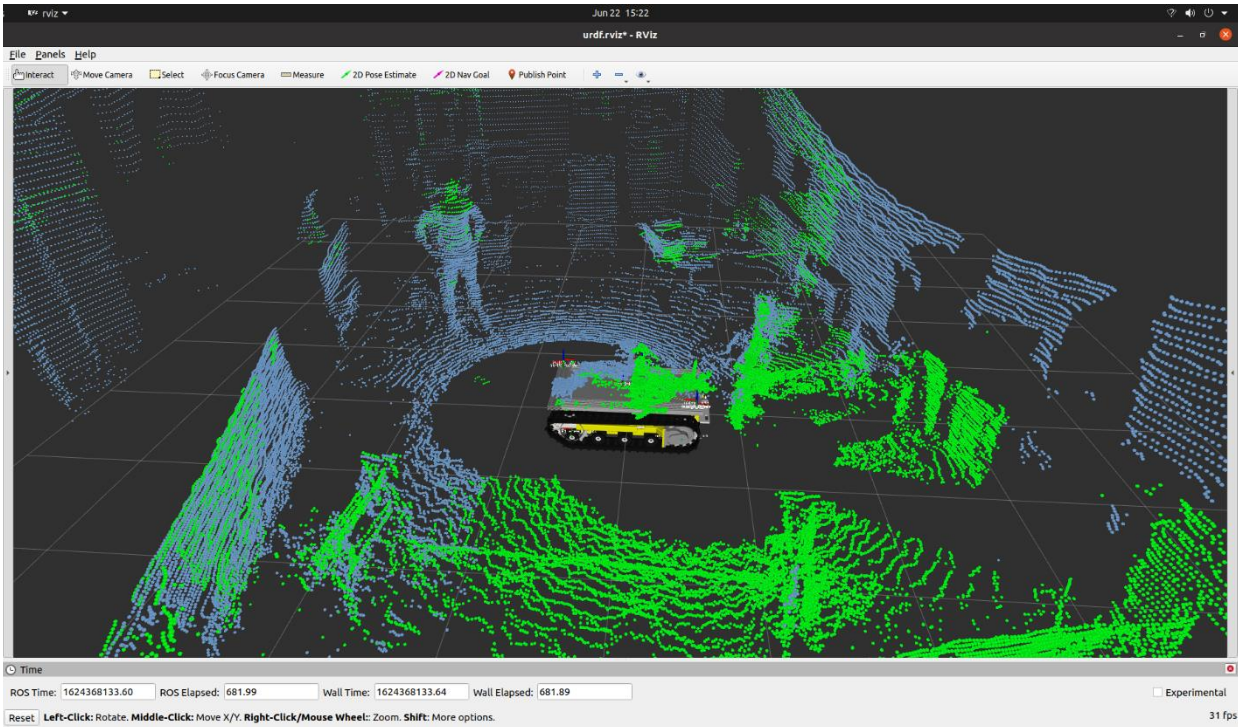


Figure 9: Screenshot from the viisualization of real sensor data while testing the position of the LIDARs.

The IMU can be seen that is placed in the center of rotation since there it provides the most accurate information about the inertial status of the robotic prototype. This configuration also enhances the ease of integration as the parameters of the IMU do not then need to be adapted, e.g., offset in one the IMUs axes of rotation. We found that the inbuilt magnetometer was somewhat prone to electromagnetic interference from the metal of the platform itself. Since we are using georeferenced heading data from the GPS, the magnetometer is intended to be disabled in use, so no real measures are necessary to combat this interference. However, for good measure and for the option of performing localization algorithms simulating the loss of GPS we are considering lifting the IMU via an aluminium profile to just above the platform surface, to reduce the effect of the interference.

The GPS antennas are the very susceptible to interference due to the emissions produced by the other sensors, especially the WiFi antennas of the routers and compute units and also the USB3 cameras. Therefore, the GPS antennas will be the ones that we will mostly experiment with until we achieve the optimal signal strength. In the previous figures, we can see the dual antenna configuration in the middle of the mobile base, aligned with the IMU, but these antennas will probably have to be moved in future version of the robot prototypes.

As part of sensor placement specifications, we need to provide usable and unobstructed space for integration of the dual arm plus two boxes of grapes (farming robot) or several boxes of grapes (logistic robot). Therefore, there is a need for a flat surface that can be used for these purposes while protecting the equipment as much as possible. Therefore, we are considering adding a second deck that has the role of separating the sensor layer from the operation/task layer. Some pictures of this configuration can be seen here:

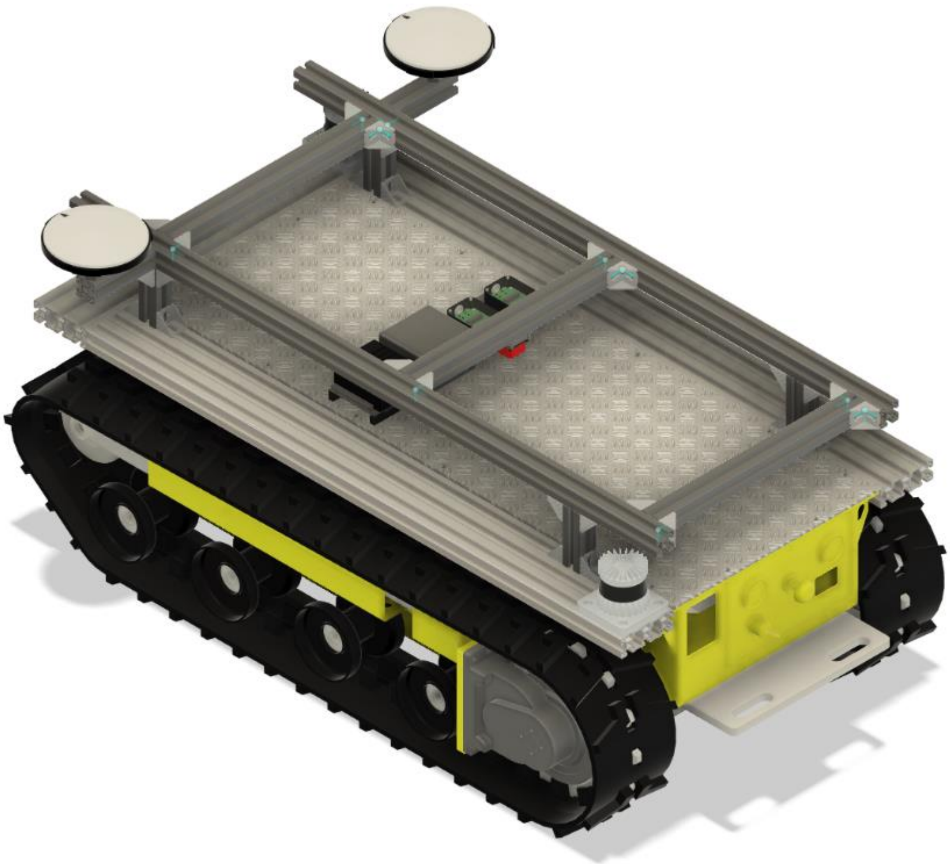


Figure 10: A new surface can be added above the previous one so that the other necessary hardware can be added. This also moves the GNSS and the IMU away from the electromagnetic interference caused by the robot base.

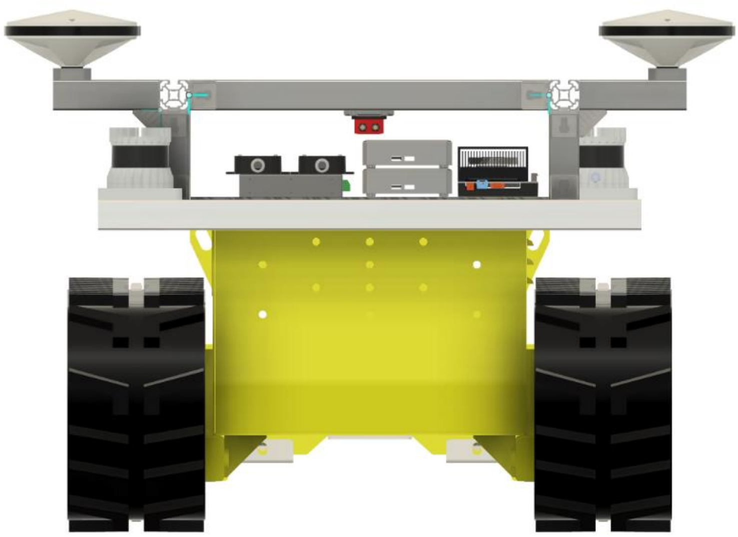


Figure 11: The "extra deck" design from the end, showing sensor vertical placement.

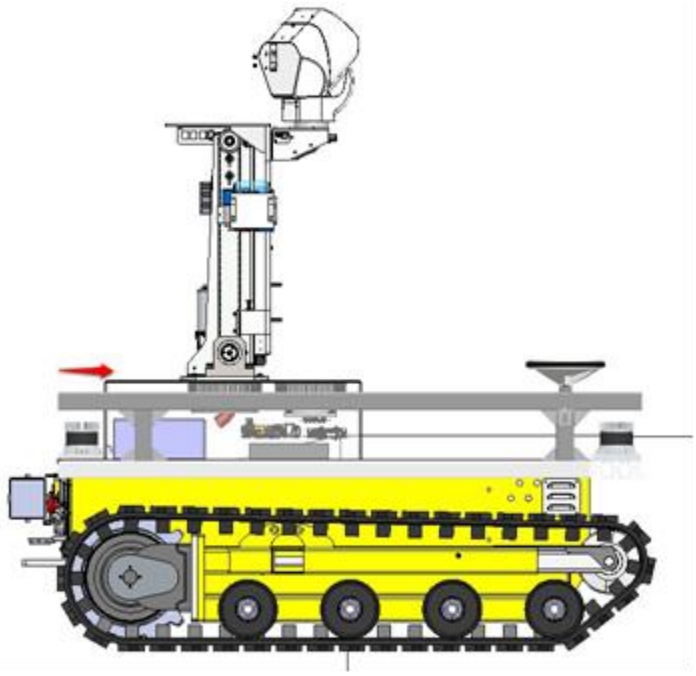


Figure 12: Side view of the "extra deck" design with the integration of the dual arm.

This design places the IMU in an upside-down position away from any magnetic metal surfaces. The GNSS antennas are moved to the front and out of the reach of the dual arm. Finally, the second deck creates a partial protection layer for several of the sensors. This concept is now under evaluation by the partners mostly involved in the customization, namely DTI and PAL Robotics.

The placement of the sensors is deliberately made to be flexible and during the project we expect to make changes according to what is needed, and the experience gained by running the robots within the vineyard. These changes will be documented in future versions of this deliverable.

2.1.3. Power management system specifications

The mobile base comes equipped with a set of four 12V 90 A h lead acid batteries in a serial configuration giving a 48V power source, providing approx. 6 hours of autonomy. The Alitrak platform comes with its own power management that powers the platform's safety components, motors, motor controllers and remote-control receiver. The platform also comes with its own power charging unit that can also perform conditioning of the batteries.

In our design we take advantage of the on-board power source and are developing an additional power management system that will supply sufficient power for all the mobile platform's sensors and the computer that will perform the autonomous navigation.

The specifications for our design are:

a) the power management system must cover the total power requirements for all foreseeable current and future sensors, thus enabling future expandability.
b) the energy supply should cover at least double the maximum calculated power consumption.

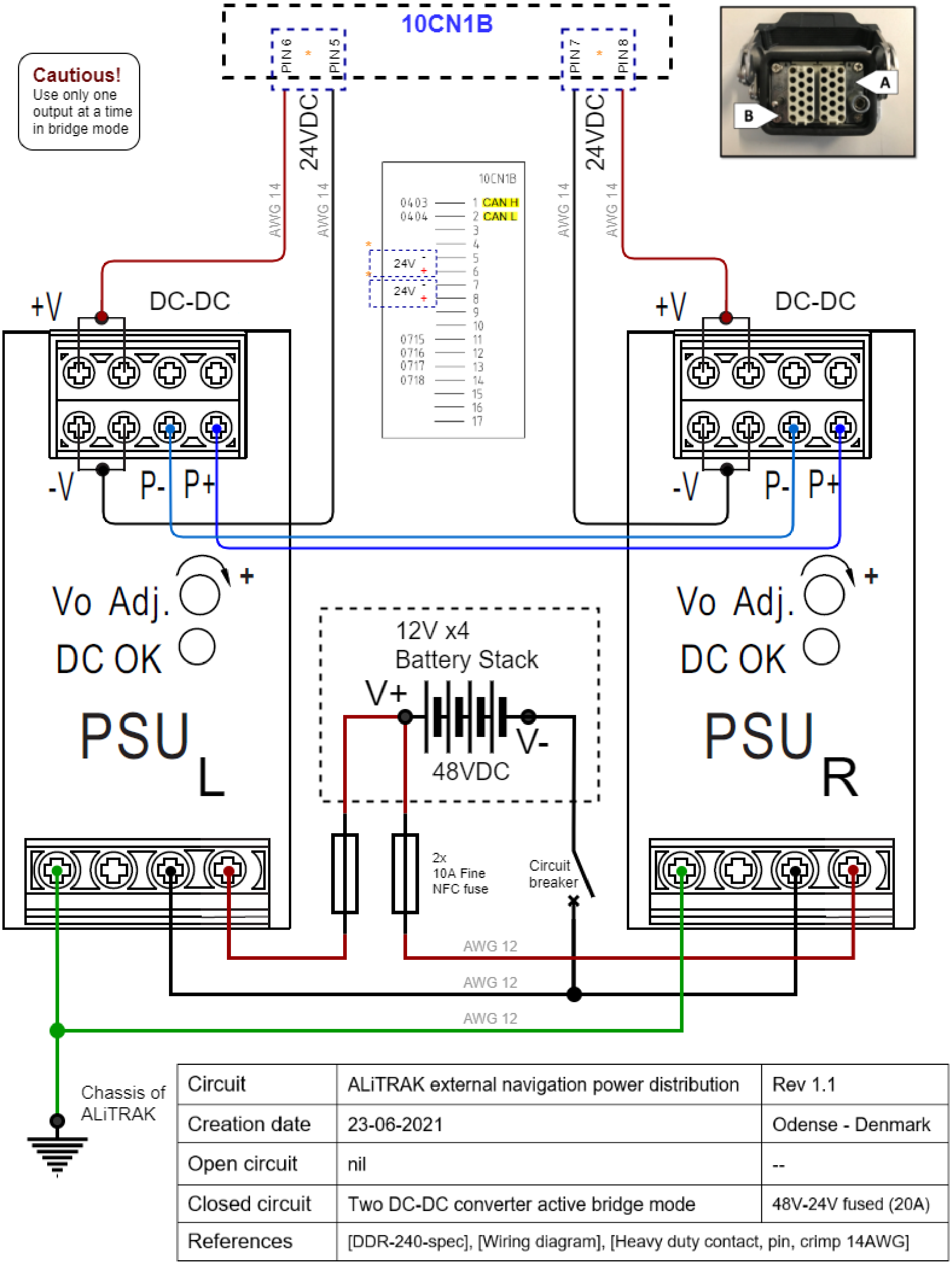
The expected power consumption is calculated in the following Table.

Table 1: Calculation of power consumption of the on-board sensors and computational components for the mobile platform.

Sensor	Voltage range (V)	Power consumption (W)
Ouster OS1-64	22-26	22 (peak on start-up)
Septentrio AsterRx-m3 Pro+	5 (USB powered)	2
SBG Systems Ellipse-E	5 (USB powered)	1
Intel NUC 11	12-24	120
Nvidia Xaver AGX	19	65
Network switch (undefined)	-	-
Network router (undefined)	-	-
Total power consumption		**210**

All expected components on the platform can be powered on by using the voltage range of 24V except for the Nvidia computation modules. For the undefined parts used for networking we are considering the use of industrial grade networking equipment which usually comes equipped with on board voltage conversion and provides in a usable input range. Therefore, we consider that the main power supply for the integration the onboard systems is 24V. Moreover, the current power consumption is estimated to be on a theoretical maximum of 210 W of power draw (excluding the networking). We consider that the power consumption is unlikely to reach that amount since the values represent the consumption either on full load or on start-up for some sensors. One more limitation, is the maximum electricity transfer through the plug found in the back of the robot which is 10A. Given the voltage and amperage of our targeted system, we consider that using a 240W power delivery system will cover our experimental needs.

In our implementation we consider adding redundancy should there be any malfunctions with the power distribution, which could result in the need of rescheduling a testing and validation period. Therefore, each power management system will be made with two DC-DC converters, connected in sync, thus a) having a better load distribution, by sharing the power load when necessary; and b) achieving redundancy in case that one DC-DC convertors seize to operate or is not operating as intended.



Circuit	ALiTRAK external navigation power distribution	Rev 1.1
Creation date	23-06-2021	Odense - Denmark
Open circuit	nil	--
Closed circuit	Two DC-DC converter active bridge mode	48V-24V fused (20A)
References	[DDR-240-spec], [Wiring diagram], [Heavy duty contact, pin, crimp 14AWG]	

Figure 13:Power management diagram for the mobile platform.

The power requirements for both the prototype dual arm and the BEM will have independent power sources and power management systems and will not affect the power management of the mobile base components. By decoupling those systems and not sharing the power source, we increase the overall autonomy of individual systems, and we also minimize the risk of rescheduling a testing and validation period.

The position of the electronics on the platform will be:

a) under the platform's main plate;
b) on top of the platform's main plate.

The ones under the main plate are expected to be permanent and will not require any interaction after installation, i.e., the main DC-DC converters that will turn the nominal 48V supply from the batteries to the 24V needed for powering on the sensors and computation components. Power from the DC-DC convertors will be distributed through the plug in the back of the mobile platform. This plug (see Figure 13) is deemed as the most appropriate since it does not require further alterations on the platform other than the addition of several pins.

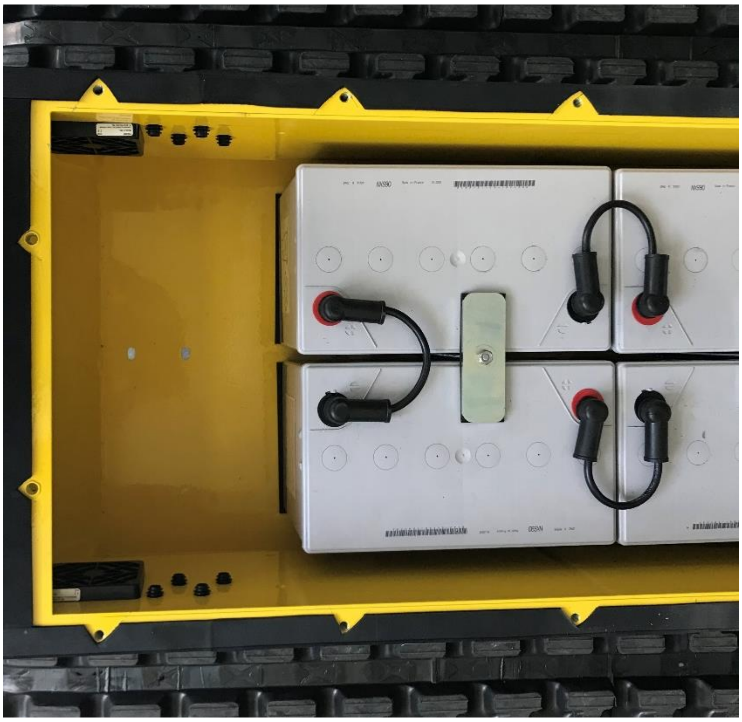


Figure 14:Compartment under the mobile platform's top plate that will accommodate the independent power sources and management systems from the dual arm prototype and the BEM.

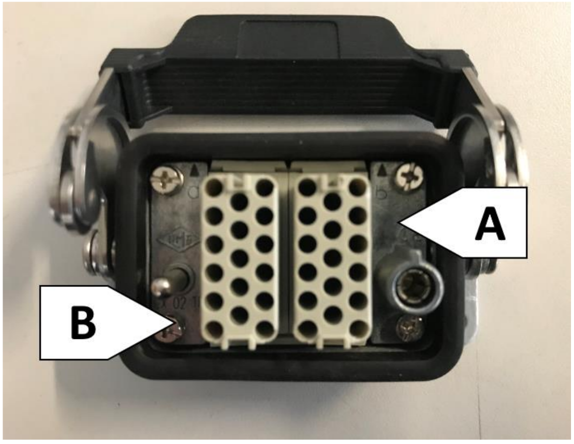


Figure 15:A picture of the plug found in the back side of the Alitrak platform. Connector A is reserved by Alitrak and should not be altered. Connector B accommodates the CAN bus connection, as well as several pins that are not assigned. These are the pins that we are going to use to get power from the DC-DC convertors to the top plate distribution.

The distribution of power to the individual sensors is going to be achieved using a power distribution blocks per DC-DC converter. The distribution blocks must be on top of the platform, near the sensors and provide an easy connection to them. We have identified that a two-level power distribution block, will allow us to have multiple positions and custom power cables with the appropriate type of power plug for each sensor, for example barrel connectors for the on-board PCs and LIDAR power supply.

2.1.4. Networking

Both robotic prototypes systems, their sensors and algorithms that are going to be developed in this project, e.g., algorithms for multi-robot coordination, are relying on a stable and fast communication method. To achieve this, the consortium has created the following specifications for the required networking and communication capabilities of the robotic prototypes:

- Fast networking: the integrated solutions must be able to not only handle the amount of data produced by the sensors but also allow the communication between robots or robot modules, e.g., communication between the mobile platform and the dual arm.
- Long range solution: the chosen communication solutions must provide the possibility for a long-range communication, e.g., communication between two robots in different parts of the field.
- Multiple client support: the solution is not only going to be used for the purposes of communication of the robots and their sensors. Moreover, multiple connections are expected as part of deployment and validation of algorithms from the researchers on the field.
- Ease of integration: networking equipment is in a lot of cases developed for stationary installations. That will potentially create limitations in power management since a lot of them have increased power consumption and odd power requirements.

For the sensors (LIDAR, RTK-GNSS), other systems (dual-arm, BEM) as well as communication between robots the main source of communication will be a local network with also WiFi connectivity. In terms of integration, we consider the use of an industrial grade WiFI router potentially coupled with a switch providing extra ports for wired connectivity. Industrial grade routers and switches have the advantages of increased robustness to heat and dust, very common in our operating environment but also a wide range of input voltages. The specification of the LIDARS, dictates that the network should sustain speeds of at least 1Gbit.

For future configurations, we consider the use of LTE technology either using 4G or even 5G (whether the technology and the network is mature in the duration of the project). This can be achieved either by buying a 4G/5G ready LTE router or by the addition of an LTE hotspot. This addition is not considered crucial for the time being, but it is something that we are planning to investigate since it will allow our robots to operate without the need for any in-field infrastructure, thus paving the way for the usage of the proposed robotic solutions also on those areas lacking digitalization and communication infrastructures.

2.1.5. Other communication modules

To take control of the mobile platform movement, manufacturer Alitrak suggested the use of CAN bus communication. This solution fulfils the requirements of the following specifications:

- Stable communication: Indeed, bad communication to the platform and especially to the platform's motors can jeopardize the safety of researchers, the condition of the equipment and the progress of the project. Therefore, a stable and reliable communication protocol is key to the control of the platform.
- Ease of integration: the communication protocol with the platform must be easy to integrate with the rest of the ROS based system. In this way interaction is natural and any issues can be troubleshooted more easily.

For the activities of CANOPIES we resort to a CAN bus reader that, based on the CAN message dictionary provided by Alitrak, will provide us with the required control over the mobile base. Currently, we are using an implementation of the CANOpen protocol in ROS, which allows us to log the odometry data coming from the mobile platform's motors. The ROS implementation of the CANOpen protocol will ultimately allow us to also control the mobile platform by assigning commands to its motors.

2.1.6. Software components

The different software components (which are mainly ROS packages) for the ground vehicle can be categorized in to 3 main categories:

1. Sensor and actuator drivers
2. Localization and navigation capabilities
3. Interfacing, usability and tools

The chosen order for the 3 categories also reflects the order of criticality of components, initiating the research activities with data collection and gradually move to autonomous navigation. The reason behind the aforementioned sequence is that the robot will not be operating autonomously through the duration of the project but will also be used for data collection and will always be able to be controlled manually.

2.1.6.1. Sensor and actuator drivers

The sensors listed in Section 2.1.1, and potential future sensors, all require drivers to deliver their data to system. As a matter of fact, the current list of sensors has native ROS drivers, but should a ROS driver not exist, then a ROS wrapper will be implemented for it.

The ground vehicle itself has no ROS interface, but there will be a ROS wrapper around its CANOpen interface so that it will be posed to control it via software.

These drivers represent the most critical software components of the ground vehicle since they are necessary to collect datasets and control the vehicle. Therefore, the computer that is physically connected to the on-board mobile platform's sensors and runs the drivers will always be mounted on the robot. Some sensors might benefit from some data processing early in the pipeline, e.g., extraction of regions of interest in lidar or camera data, and such processing could be done on such computer in order to limit the data sent out over the network to the other computers.

2.1.6.2. Localization and navigation capabilities

The components in this category represent the autonomous capabilities of the robot.

Localization component uses all the sensor data to reason about the precise location and movement of the robot, while the navigation components enable path planning and motion control of the robot.

These components will be under active development throughout the duration of the project with intermediary milestones where different capabilities are provided. While these capabilities are inherent to the ground vehicle itself, but also useful for the robotic prototypes as a whole, there is a need for interfacing with other hardware and software components such as the dual-arm system or the BEM.

2.1.6.3. Interfacing, usability and tools

These components represent the interfacing between the different subsystems on the robot (e.g., sensors, ground vehicle, dual-arm) and the tools to make use of each of them. These tools will offer the capability of e.g., setting up routes, waypoints, missions, and other things that make use of the autonomous functionality of the robot. For this to be accomplished, the consortium will define interfaces and APIs between the different subcomponents that enable a user to use the robot from a higher-level abstraction without worrying about the interplay between e.g., the ground vehicle and the dual-arm system.

2.2. Dual-arm system with actuated torso

In CANOPIES, PAL wants to further advance its manipulator platform and develop a product in a new niche that will create opportunities in worldwide markets in the agricultural segment, especially in agronomic manipulation where market ready solutions are scarce.

We chose the TIAGo++ dual-arm robot from partner PAL Robotics (see picture) to provide the manipulation capabilities. This will be adapted to communicate with the mobile base chosen for the two robotic prototypes instead of its current base, creating a version of the upper-body that is standalone and can be mounted on different mobile bases or in static work stations. Several mechanical and electronic redesigns will be needed to increase its capabilities and adapt it to the project requirements. The starting specifications of the TIAGo++ robot are the following:

- Differential drive base
- Base footprint: Ø 54 cm
- Weight: ~ 100 kg
- Torso lift stroke (prismatic joint): 350 mm
- 7 DoFs each arm
- Arm payload (without end-effector): 3 kg
- Arm reach: 87 cm
- Pan-tilt head with a RGB-D camera
- Optional Nvidia Jetson TX2

Figure 16: Current market-ready solution Tiago++ developed by PAL Robotics.

The new design will include:

- An additional DoF in the torso, for rotating about itself to increase its already large workspace. The new DoF will have a minimum rotation range of 300°. The prismatic joint able to raise and lower the whole upper body will be kept in the new design.
- A new version of the arms with a) better compliant control to increase safety when collaborating with humans and b) better sensing of potential collisions or contacts with the environment. The arms will have a payload of 3 kg (without end-effector) in the worst kinematic configuration, i.e., arm totally extended parallel to the ground. The maximum reach of the arms (without end-effector) will be around 87-90 cm.
- Series Elastic Elements (SEE) in each joint of the arm for torque sensing.
- Brakes in the first 6 joints of the arms to comply with safety regulations which require that, under a power cut, the arms of the robot must remain steady.
- New communication bus to increase the bandwidth: EtherCAT will replace the current CAN bus in TIAGo++'s arms.
- The arms will include a standard communication bus, probably USB 3.1, for integrating sensors on the end-effectors or near the end-tip of the arms.
- Torque control of the robot arms: the SEE will enable torque control and hence improve the compliant control of the arms, which is of key importance to operate safely around humans.

The new torque control will prevent the exertion of strong forces against a person or obstacles, which is a very important asset in any collaborative application.

- 1x Pan-tilt mechanism with a payload of around 1 kg to attach the sensors required to implement the agricultural tasks.
- 1x Speaker for the robot to synthesize voice and audio when needed.
- 1x Stereo microphone.
- 1x Expansion port including at least 2x USB, 1x GigE ports to connect sensors on the top part of the upper body.
- ROS API for integration purposes.

Furthermore, in order to make the new version of TIAGo++ upper body self-contained, i.e., not dependent of its former mobile base, and hence being able to operate autonomously as a standalone robot, the following components will be included in the upper body:

- 1 or 2 battery packs
- 1x charging port.
- 1x Power management board
- 1x Computer
- New end-effector with under-actuated fingers and different custom add-ons to enable the attachment of tools as required by the agricultural operations.

2.2.1. Prototype mechanical design

PAL is working on two new actuators with embedded electronics to implement the new torque control arms. The first version of the actuators will be used in the 5 first DoF of the arms as they will provide higher torque and the second smaller version of the actuator will be used in the last 2 DoF where less torque is required. This new kinematic architecture will replace the one used in TIAGo++ which includes a differential mechanism implementing the last 3 DoF of the arm in what we call a "wrist". This modification will reduce the backlash in the joints included in the former wrist and will improve their controllability, especially in different effort modes.

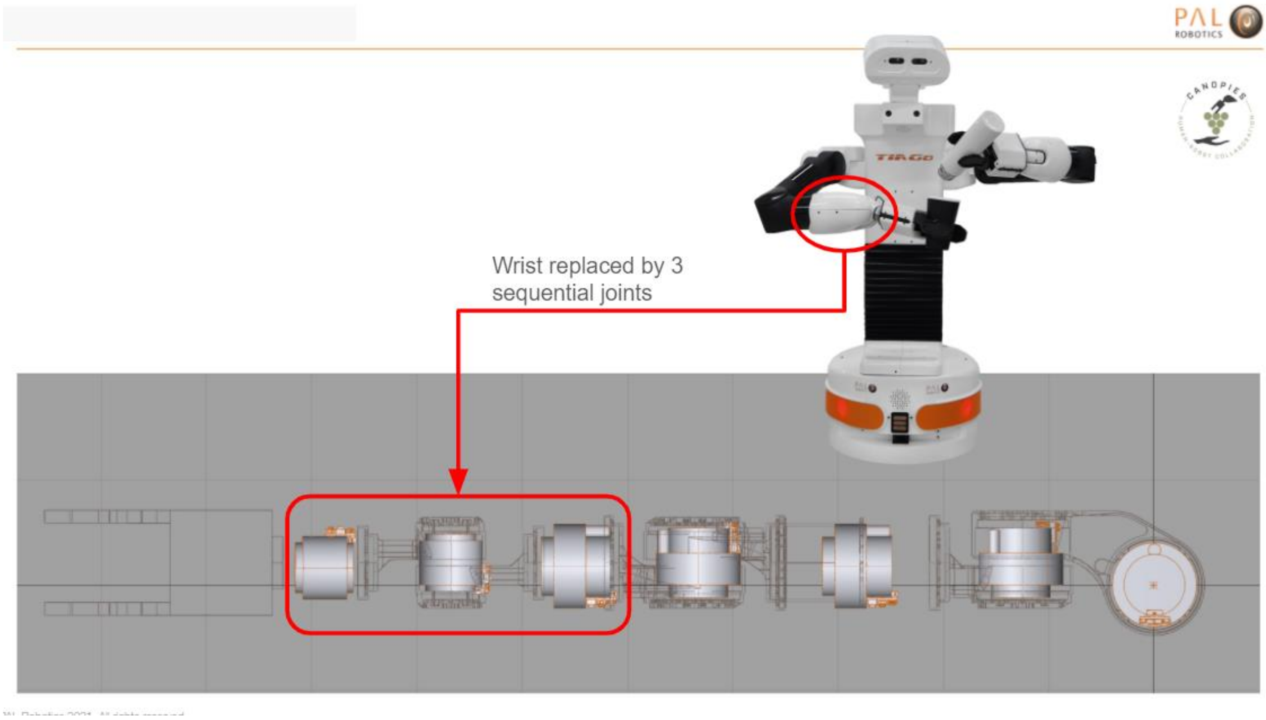


Figure 17: Representation of the prototype arm design. The wrist is now replaced by 3 sequential joints.

PAL considered two possible TIAGo++ upper body configurations for the robot:

- One where the batteries, power management board and computer are placed inside the Alitrak base front compartment.
- Another one named "self-contained upper body" where everything (batteries, computer, and power board) is placed underneath the TIAGo++, thus increasing its height.

Note that the upper body will (according to the current design ideas) be placed on the rear part of the Alitrak base being able to rotate at both sides to do the agricultural tasks (pruning, recollection, etc.).

Discussions with CANOPIES partners concluded that the extra reach of the self-contained upper-body resulted in the better option. Considering the possibilities to add an additional level, i.e., extra deck design described in Section 2.1.2 for the protection of sensors and creation of an unobstructed workspace, adds points to the self-contained upper-body configuration. The self-contained upper-body concept complements the aforementioned design since it saves space between the decks which can be utilized by sensors and future devices. Therefore, the dual arm agronomic system prototype will use this option from now on, but in this deliverable, we describe both just for completeness.

Both solutions that were considered for the TIAGo++ upper body configurations are shown in the following figures:

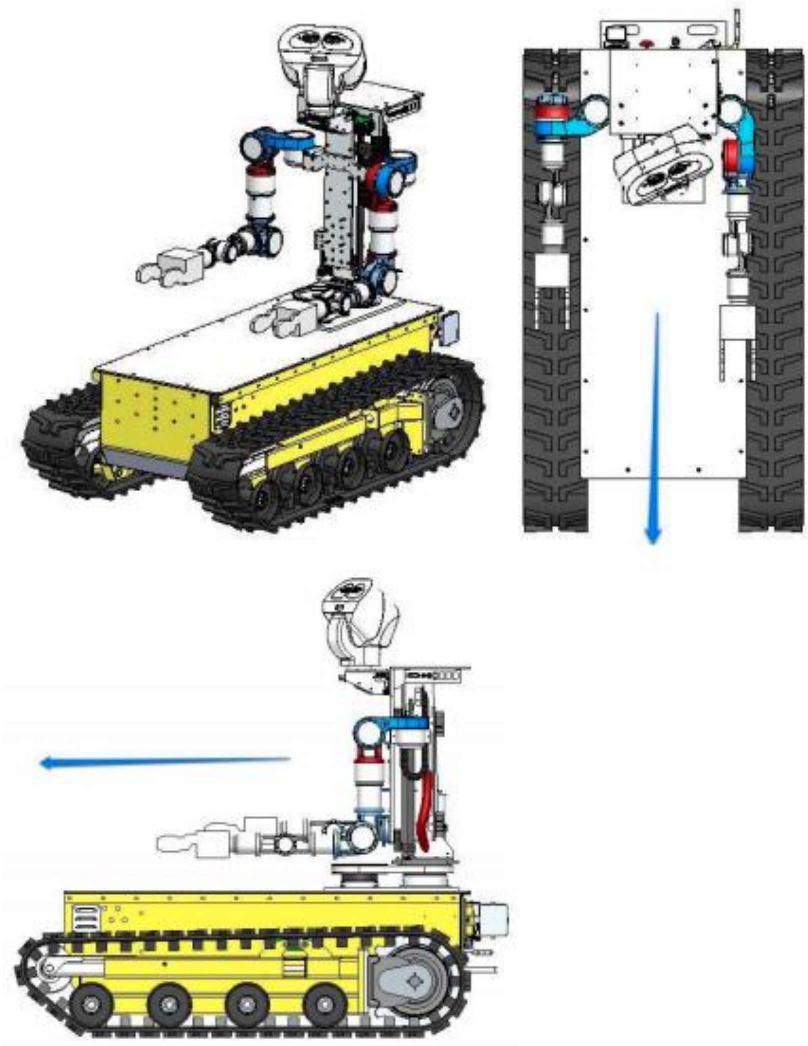


Figure 18: The first solution, where the batteries, power management board and computer are placed inside the Alitrak base front compartment (and therefore are not visible).

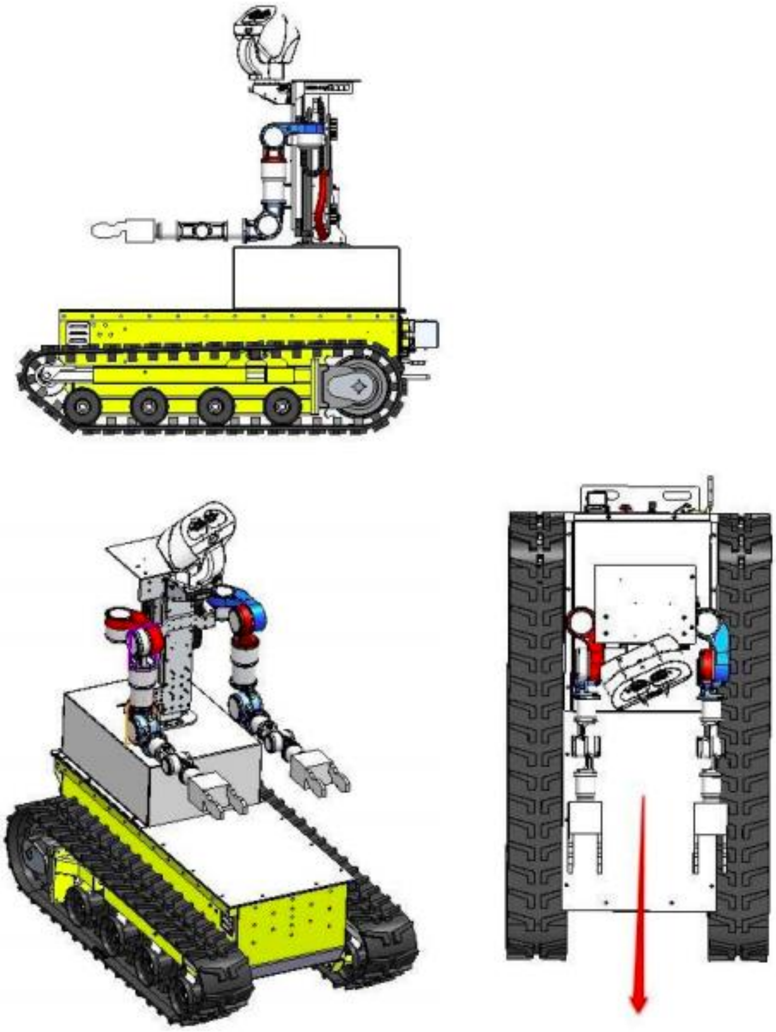


Figure 19: The chosen solution where everything (batteries, computer and power board) is contained in the box shown below the body of TIAGo++.

2.2.2. Reachability study

An investigation of the robot reach was conducted for both the options presented above and for the chosen option with an additional rotation DoF on the torso. The results are illustrated below:

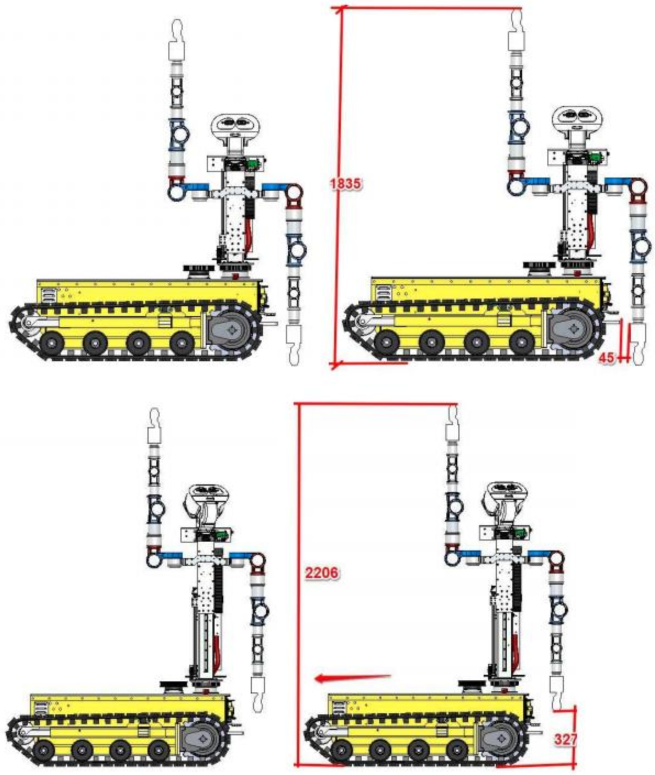


Figure 20: Robot reach for the solution where the batteries, power management board and computer are placed inside the Alitrak base front compartment. Top: prismatic joint completely retracted; bottom: prismatic joint completely extended

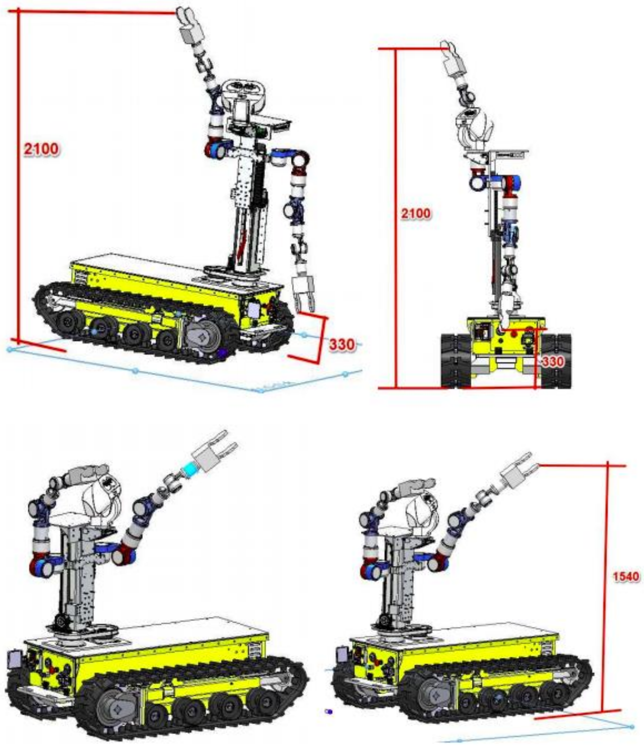


Figure 21 : More reach measurements for the solution where the batteries, power management board and computer are placed inside the Alitrak base front compartment.

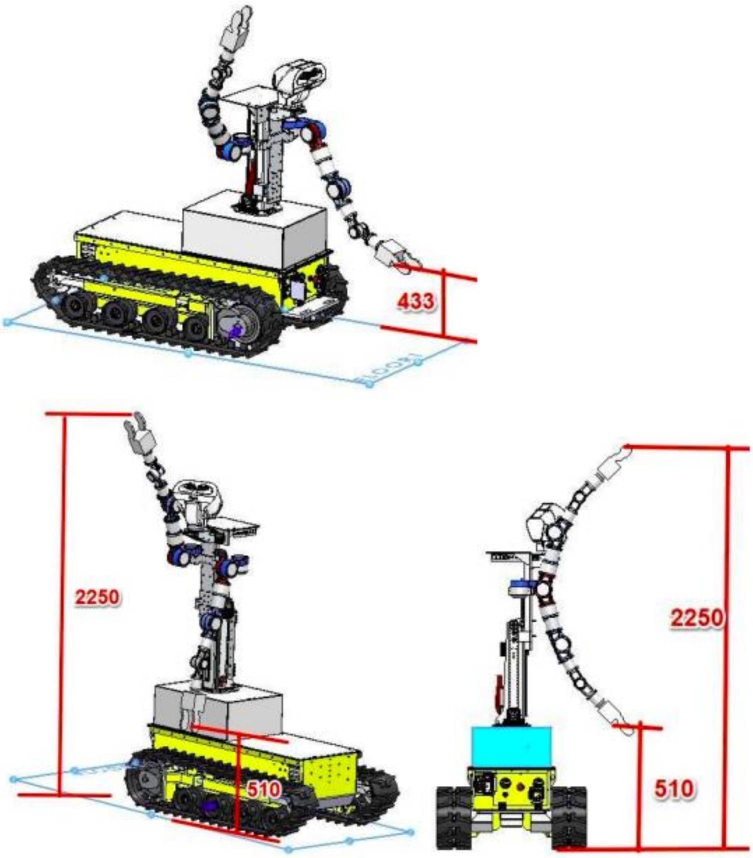


Figure 22: Reach measurements for the chosen solution, where the batteries etc. are placed in a box directly under the TIAGo++.

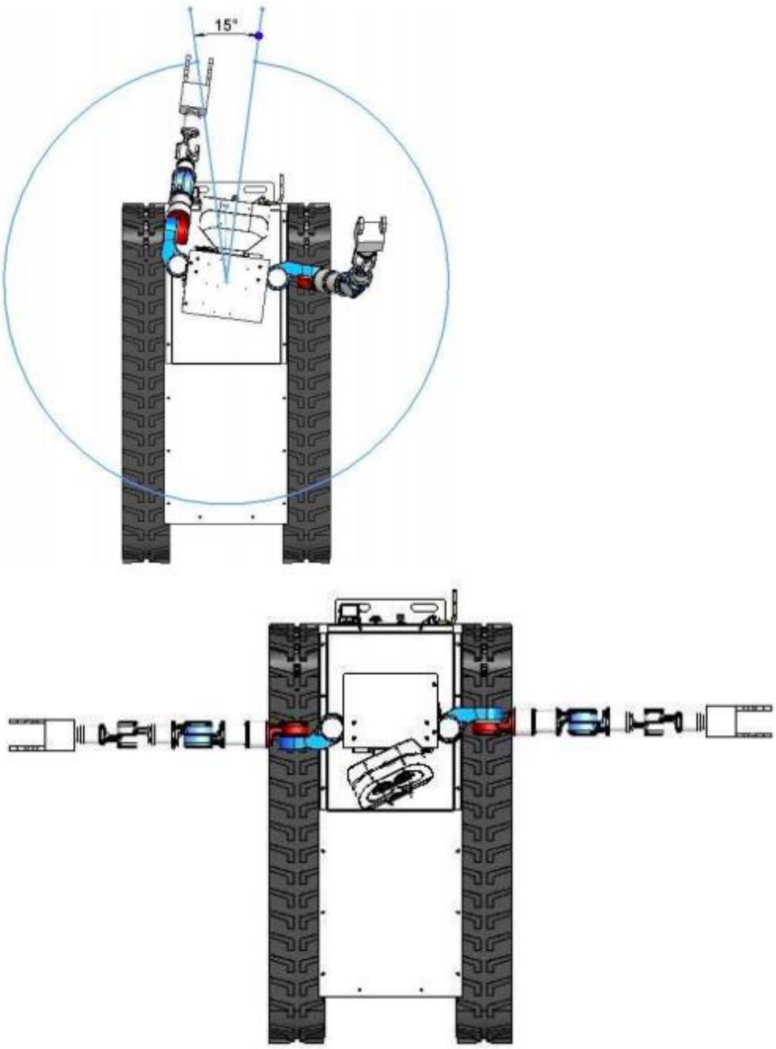


Figure 23: Robot reach with a rotational joint under the torso.

The extra layers on the mobile base will also affect the height and the workspace of the dual-arm robot, but exactly how this will affect the reach will be studied in the coming months and discussed in the next version of this deliverable -- the design pre-study is currently still ongoing.

2.2.3. Power management

The new dual-arm robot will contain 1 or 2 battery packs of either 36 V 20 Ah or 48 V 20 Ah or similar. The power management board will supply power to all the sensors and actuators on the robot at the appropriate voltage.

2.2.4. Networking and module communications

The arm communication bus will be migrated from CAN to EtherCAT to obtain a higher bandwidth, which is needed to implement effective torque control. Furthermore, all the sensors included in the arm as well as the new communication bus will pave the way for implementing a broader set of controllers for controlling the force applied by the robotic arm-like impedance control, i.e., at joint level and in operational space.

The dual arm prototype will be equipped with multiple connectivity options including a WiFi interface, plus Bluetooth 5.2 and two WiFi antennas. The dual arm prototype will have connection to the mobile base using a Gigabit Ethernet, thus allowing for high bandwidth communication required for the sub-system coordination..

2.2.5. Sensorial equipment considerations

The pan-tilt mechanism on top of the robot and the top of the back of the robot will have machined plates with multiple mounting points in order to attach sensors or devices needed by other partners.

Power supply and distribution will be available near the top part of the upper body in order to supply power to the sensors or devices needed by other partners on that part of the robot.

The end part of the arms of the robot will provide a USB port to connect a camera or other sensors compatible with this bus.

2.2.6. Software components

The internal software structure of the dual arm that will assist the integration with the partners' packages is briefly presented. The software structure provided for the dual arm is classified into three categories:

- Packages from the official ROS distribution.
- Packages specifically developed by PAL Robotics (which are included in PAL's own distribution),
- Packages developed by the partners.

The three categories of packages will be installed in different locations of the internal storage of the compute unit used for the dual arm system. The ROS distribution packages, and PAL packages will be installed in as read-only partition. Note that even if these software packages are modified or removed, at the partner's own risk, a better strategy is to overlay them using the deployment tool. The deployment tool is a script PAL Robotics provides with the development environment. The same deployment tool can be used to install ROS packages in the user space.

2.2.6.1. Interfacing, usability and tools

A WebCommander website hosted by the compute unit on bord of the dual arm prototype and will serve as an interfacing tool. The developed tool will report through visualizations the state of dual arm hardware, applications and installed libraries, as well as tools to configure elements of its behavior. This tool will be accessible from any modern web browser and from any user that will be connected to the dual arm's network.

2.2.7. Basic dual arm control

A special ROS-based software framework is required to make the joint torque controllers of the prototype dual arm accessible for implementation of mid-level control, i.e., exposing a hardware abstraction layer with open interfaces. The dual arm will expose controllers for the upper body parts through ROS topics, actions, and messages corresponding to [ros_control] architecture. The dual arm prototype will be provided also with a motions engine in order to repeat predefined motions involving joints of the upper body. As part of the development in this project, a default library with several motions will be provided, and partners will be encouraged to add new motions that will be repeatable at any time. The motions engine provided with the dual arm will be based on the play_motion ROS package. This package contains a ROS Action Server that acts as a demultiplexer to send goals to different action servers in charge of commanding different groups of joints.

2.3. Agronomic end-effectors

The agronomically adapted dual arm design will be accompanied by custom gripper designs that will allow the execution of the harvesting and pruning tasks. We plan to replace the mechanical interface of the custom TIAGo++ arm end-tip by one widely used in industrial robotic arms, i.e., the one specified in ISO 9409:

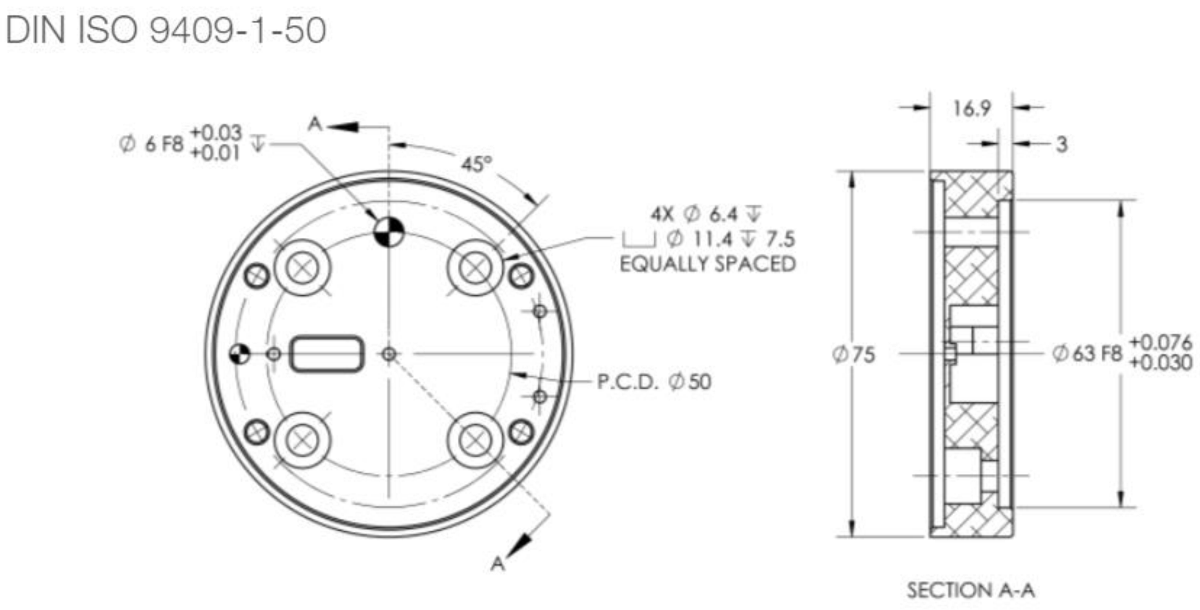


Figure 24: ISO 9409 specifications for the standard industrial arm end tip.

This will pave the way for integrating one of the most common industrial end-effectors on the market, the Robotiq 2F gripper, which has the advantage of having underactuated fingers and customizable fingers.

The plan for designing the required end-effectors for CANOPIES is as follows:

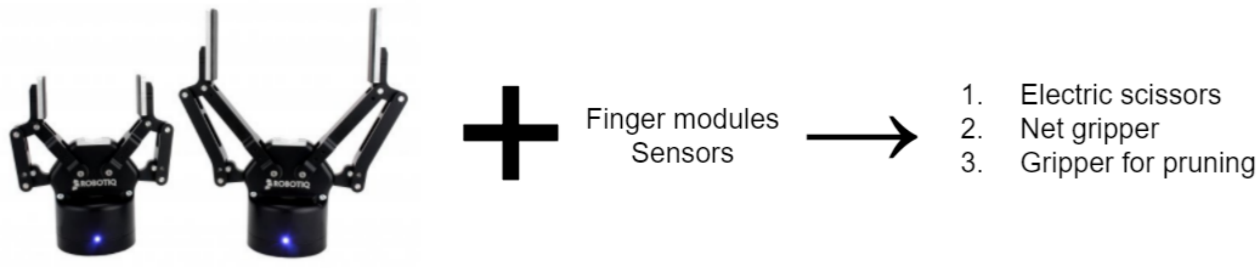


Figure 25: The Robotiq 2F gripper and its conversion into the necessary agronomic tools.

The Robotiq gripper 2F-85 or 2F-140 will be integrated with the new torque control arm and several finger modules will be designed and manufactured to implement the different agricultural operations.

Design of the agronomic end-effectors will start in M8 and more details about the strategy finally adopted will be found in later versions of this document.

2.3.1. Prototype mechanical design

The integration of the Robotiq gripper in the new TIAGo++ arm will require:

- Design of an adaptation flange
- Electronics for communication between EtherCAT and RS-485
- Power supply adaptation for the gripper
- Design of custom finger modules to have different versions of end-effectors able to perform different agronomic operations.

2.3.2. Sensorial equipment considerations

The adaption flange to attach the Robotiq gripper will have mounting points to attach some sensors close to the end-effector.

2.4. Agronomic perception

General analysis for target detection, localization and estimation of grape quality and ripeness: There are different scenarios with clearly different features, namely:

I. Detection of grape clusters and of the peduncle for harvesting.
II. Detection of canes and buds for pruning.
III. Estimation of grape quality and ripeness in term of sugar contents and of general absence on exterior imperfections.

Some of these scenarios require detection rates that allow for integration within a control loop, while others are required for planning the pruning and harvesting and do not require such a constraint.

Also, both harvesting and pruning will be performed in the same environments, so there are common elements (specific distribution and dimensions of the vineyard) that will impact sensor performance and usefulness.

2.4.1. Sensorial equipment for agronomic perception

We are considering the following type of sensors, which have to be validated in the vineyard field in order to find the most suitable selection:

Vision-based system:

For detecting and locating the items of interest e.g., bunches of grapes or buds on vine stems, RGB images and 3D point clouds will be collected. These sensor data will be considered as type of input for training the developed agronomic perception algorithms. Image and video data collected will be enhanced with additional information, such as GPS position or grape sugar content. Preliminary field tests were conducted to test several active RGB-D sensors that were already available to the Consortium's partners. This test allowed us to evaluate the effectiveness of each sensor under real conditions, in the open field under direct sun illumination. From these preliminary tests, it was clear that only RGB-D specifically thought for outdoors operation, can provide usable images and point clouds. Specifically, the sensors that we are considering for the initial data acquisition are:

- RGB-D sensors (Realsense D435i, Realsense D415, Minteye stereo camera)
- Stereo vision sensor (ZED 2, passive RGB-D stereo camera with deep learning depth estimation)

Multispectral sensor:

The possibility to use a multispectral camera will be evaluated during the project in order to leverage direct correlation between the grape's sugar content and some specific wavelengths. However, the actual useful wavelengths are not clear at the time of the drafting of this version of the deliverable, since all the available scientific results on the topic are conducted using hyperspectral cameras in controlled lab environments, and not with multispectral cameras under direct sunlight. This aspect requires further investigation to make sure that it is possible to collect this f information of the grape's ripeness levels in the field, and to determine the exact multispectral sensor that is needed.

GNSS-RTK sensor:

For agronomic purposes the position of a recoding is very important since our operational environment is alive and changing with the pass of time. For example, it is very important to not only visualize but also geo-reference a grape bunch and be able to observe the changes in its sugar levels. Therefore, the RTK-GNSS system that is already available with the platform will share its information which will be fused in our visual datasets.

2.4.2. Sensor placement

The exact location of the sensors will be decided throughout experimentation, since the actual vineyard geometry, grape bunches position, and any other source of uncertainty in data collection will be discovered during the summer season of the first year. At the same time, we can make some working hypothesis:

Vision-based sensors:

- Cameras and RGB-D sensors will be probably placed high enough to be able to observe a good portion of the grape bunches at a horizontal level. This implies that these cameras will be installed on the torso or the head of the dual arm manipulator, or on a separated beam structure. The exact height and inclination will be decided throughout experimentation.

- For the picking and pruning activities, it is expected that some of the cameras will be potentially placed on the robot arm, wrists, or end-effector of the dual arm prototype.

Multispectral sensor:

- The multispectral camera that will be considered for the project will be required to have optics similar to the one used for the stereo vision system. This is required in order to collect both RGB-D data and multispectral data from the same perspective or a calibrated perspective between the two cameras. Therefore, the multispectral sensor will be placed with the same considerations given for the aforementioned vision-based sensors.

RTK-GNSS sensor:

- On the mobile platform, see Section 2.1.3. The placement and height of the antennas and the eventual interference of the cameras with the GNSS system will be evaluated on the field.

2.4.3. Power management

For the sake of the agronomic perception task, we expect the main sources of power consumption not be the cameras themselves but the computational components required for the processing of the data (Intel NUCs, NVIDIA Jetsons or NVIDIA Xavier).

The considered stereo, RGB-D and multispectral cameras are USB-powered devices and do not affect the overall power consumption since their power supply is through the computational units that they are connected to.

In the current project phase, we also have discussions about the possibility of additional illumination that will assist the performance of the cameras by providing stable illumination conditions. Illumination could be an additional source of power consumption, however at this point there are no plans to add an external power source.

2.4.4. Module communication

All the considered devices are communicating with the computational units with high bandwidth USB3.0 and 3.1. Therefore, the compute units should have multiple ports and be able to sustain the required bandwidth. In case that some of the agronomic vision sensor requires an Ethernet connection, then this can be taken care of by the Gbit networks integrated on the mobile base and the dual arm prototype.

2.5. Box-exchange-mechanism

A big part of the multi-robot coordination academic efforts is the development of the prototype BEM for both robotic prototypes. Since the two robotic prototypes are different in form, we also expect that the developed mechanisms will have different specifications.

Since the BEMs are prototype mechanisms that need to be developed from the ground up, we developed a set of parameters that will allow us to identify the requirements and find the limitations of various concepts. In detail,

1. Category: refers to the general class of the specification, i.e., whether it is specifications from the environment, budget related, the physical space on the robot or are related to the overall processes that are required for the successful operation of the BEM.
2. Sub-category: describe smaller traits of the previous classification thus allowing us to focus on specifications of specific parameters.
3. Severity: is the rating of how important the requirement for the operation of the BEM prototypes is.
4. Description: sort overview of the requirements.
5. Requirement: the identified specification requirements themselves.
6. Robot prototype: sort identifier of which robot prototype is concerned for the described specification.

A detailed table of all specification can be found on Table 2.

Table 2: Specifications for the BEM mechanisms

Category	Sub-category	Severity	Description	Requirement	Robot prototype
Environment		Must have	ingress protection (IP rating)	IP54 or better	both
Physical	Space	Must have	max. footprint on farming robot	850x900 mm	farming robot
Physical	Space	Must have	box positioning on farming robot	10 cm before the maximum reach of the dual arm	farming robot
Physical	Space	Must have	max. footprint on logisitc robot	850x1500 mm	logistic robot
Physical	Space	Must have	max. Height on logistic robot	1.5m	logistic robot
Physical	Box	Must have	box dimensions	approx. 60x40x13,5 cm	both
Physical	Box	Must have	box weight	up to 10 kg	both
Physical		Best effort	accessibility for operator	operator needs to have access to robot arms	

Price		Best effort	max. Price of modules	budget is 12k€ for farming robot, 24k€ logistic robot	both
Process		Best effort	min. boxes on farming robot	2	farming robot
Process		Best effort	min. boxes on logistic robot	4	logistic robot
Process	Alignment	Must have	max. roll alignment error	±10 deg	both
Process	Alignment	Must have	max. yaw alignment error	±20 deg	both
Process	Alignment	Must have	max. Out-of-horizontal alignment error	±10 deg	both
Process	Alignment	Must have	max. Horizontal alignment error	±100 mm	both
Process	Alignment	Must have	max. Vertical alignment error	±50 mm	both
Process	Alignment	Must have	max. gap between robots	±150 mm	both
Process		Must have	locking / securing boxes during movement	boxes must stay in place when traveling over uneven terrain @ 4 km/h	both
Process		Best effort	docking orientation of robots	(Under discussion)	both
Technology		Best effort	TRL	6	both
Technology		Best effort	actuator types	electrical	both
Technology		Best effort	sensor types	rugged enough for environment	both
Technology		Best effort	power supply	(To be dictated by the final design)	both
Technology		Best effort	distribution of mechanisms	active components only on one robot	both
Usage		Must have	flexibility	easy exchange of components and changing of structure	both

Currently we have defined two prototypes sets of the original BEM mechanisms. These are based on the initial idea about the BEM mechanisms including several additions to the initial concept. The first concept is of the BEM is based on a conveyor belt-based solution with the addition of mechanical alignment mechanism. This concept is depicted in Figure 24. The concept requires for both robot prototypes to have an active mechanism where boxes will be exchanged with the conveyors on both robots pushing-pulling the boxes in coordination. The addition to the original concept is the use of springs or other flexible mount that will provide with additional 6 DoF over a small distance. Moreover, during the alignment process of the platforms both platforms have guides that will remove some of the potential horizontal alignment errors.

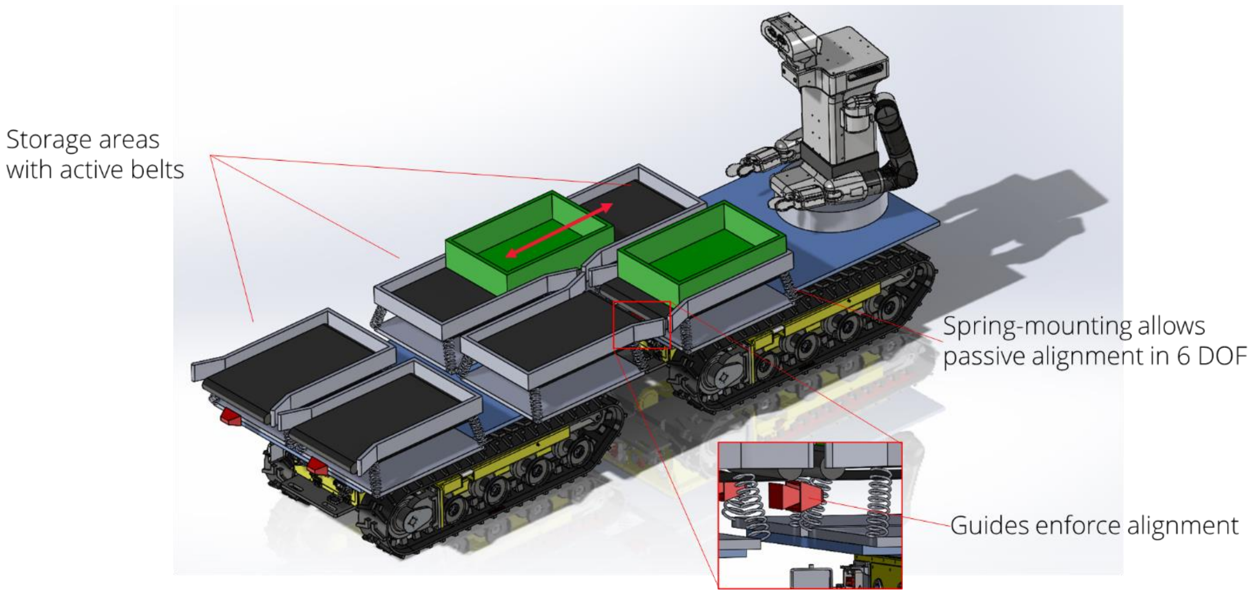


Figure 26: BEM concept with mechanical alignment.

The second concept is based on active and articulated conveyor belts, where the conveyor belt itself has 2 DoF, thus performing the exchange of boxes providing flexibility on the alignment strategies. This concept is depicted in Figure 25.

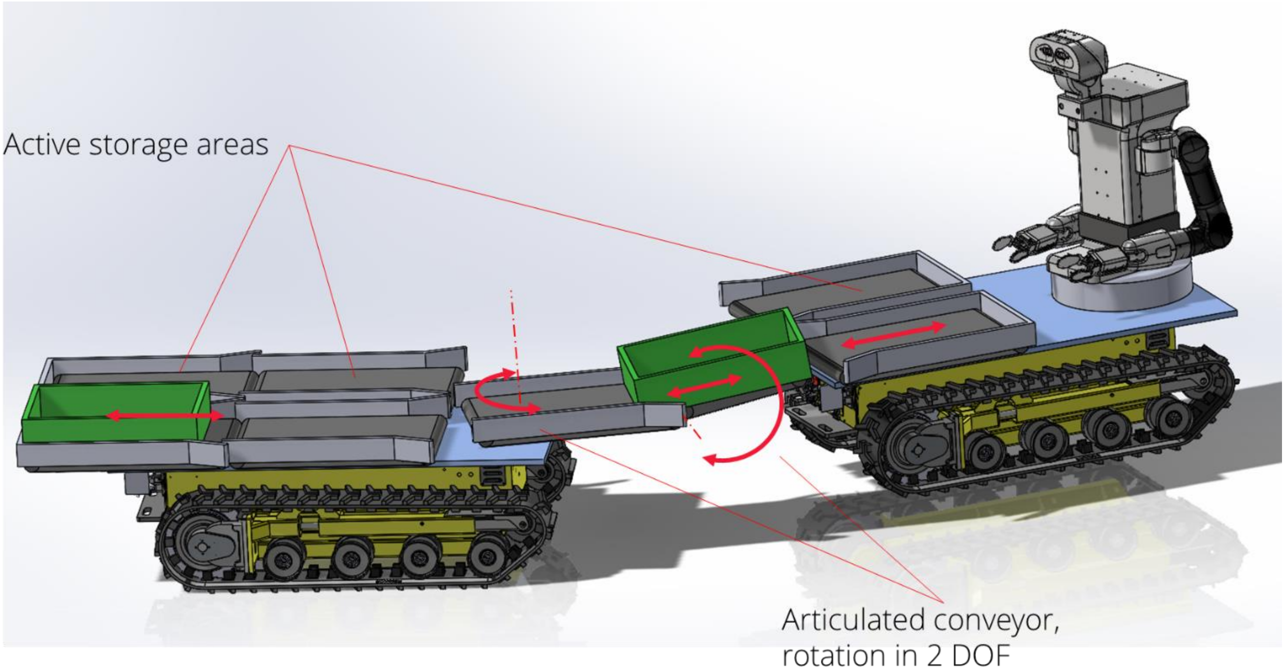


Figure 27: BEM concept with articulated conveyors.

Based on the aforementioned specifications we create a comparison that can be found in Table 3. This comparison will also serve as a tool for exploring the feasibility of future concepts.

Table 3: Comparison between current BEM concepts

		Conveyor based solutions	
		mechanical alignment	articulated conveyor
misc			
Docking orientation		head-to-head	1 of any
# empty slots for exchanging full for empty box		2	2
KPIs			
hardware complexity		medium	high
software complexity		low	medium
overall robustness		?	?
active mechanisms on…		both	both
off-the-shelf-components		medium	few
number of active mechanisms		4+	4+
Requirements			
max. footprint on farming robot	850x900 mm	+	+
max. footprint on logistic robot	850x1500 mm	?	?

max. Height on logistic robot	1.5 m	?	?
TRL	6	+	?
min. boxes on farming robot	2	+	+
min. boxes on logistic robot	4	o	o
ingress protection (IP rating)	IP54 or better	+	o
max. Price of modules	budget is 12k€ for farming, 24k€ logistic robot	+	?
max. roll alignment error	±10 deg	+	+
max. yaw alignment error	±20 deg	+	+
max. Out-of-horizontal alignment error	±10 deg	+	+
max. Horizontal alignment error	±100 mm	+	?
max. Vertical alignment error	±50 mm	+	+
max. gap between robots	±150 mm	+	+
sensor types	rugged enough for environment	+	?
box weight	up to 10 kg	+	+
distribution of mechanisms	active components only on one robot	-	-

2.6. Safety equipment

Safety of the people and researchers around the robot is paramount to the successful completion of the CANOPIES' activities. Therefore, an appropriate safety installation for the robot prototypes must fulfil the following specifications:

1. Multiple safety solutions: the designed and integrated safety solutions must be redundant, e.g., with the inclusion of multiple emergency buttons, and focus on multiple safety approaches such as on-board and wireless emergency buttons.
2. Accessibility in case of emergency: all safety solutions must be always accessible by personnel all around the robot. So, in the case of an emergency the emergency stops can be triggered from various points on the robot.
3. Constant overwatch: a person must be constantly in charge of the safety during the robot's operation. Therefore, it is paramount for the person not only to have physical access with on-board solutions but also with a wireless solution that will allow them to remotely stop the operation of the robot.

The current safety design includes the use of four components:

a) The on-board emergency stop button in the back side of the robot platform: on the back of the robot is already integrated an emergency button. As part of the development, we keep this space free of any other additions in order to keep the emergency button as accessible as possible.
b) Wireless emergency stop on the platform's controller: the wireless controller of the Alitrak platform already comes integrated with an emergency stop, thus creating a wireless emergency stop solutions that is accessible remotely at all times.
c) Heartbeat between the platform and controller: Alitrak integrates the receiver of the wireless controller with the motor control in such as way if the communication is lost from either side, then the platform is going into an emergency stop.
d) Wireless emergency stop system: Additionally to the on-board Alitrak systems we are working towards the integration of the Kar-tech wireless e-stop solution[5] which will provide us with an additional safety component. The system was chosen because of its low integration effort and ergonomic design of the wireless emergency stop. Moreover, the system allows for the addition of more physical emergency buttons.

Currently the consortium is under discussions for the inclusion of more physical emergency buttons and their various placement options on the farming and the logistic robot prototype.

2.7. Software specifications

2.7.1. Operating system and basic development components

The backbone of the software architecture for both robotic prototypes and its comprising subsystems, is a combination of the Ubuntu operating system and the ROS middleware framework. Specifically, the consortium has decided for the use of Ubuntu 20.04 and ROS Noetic, both of which are long term support versions lasting until 2025.

All selected sensors and developed robotic subsystems are compatible with the Noetic version of ROS. Some specialized components might require different hardware and software, e.g., artificial intelligence and machine/deep learning algorithms or hyperspectral cameras. In this case, the sensors will be integrated to the rest of the ROS architecture through ROS wrappers.

2.7.2. Software distribution

Most of the software developed in the project will take the form of ROS packages that are compatible with the chosen OS and ROS version. The consortium has decided that packages will be hosted on the CANOPIES project Github page and will be made available for use by all the partners. Some packages will be open-source and contain source code, while others will only be distributed through binaries or similar methods, e.g., docker images.

[5] https://kar-tech.com/wireless-estop-system-multiple-receiver.html

The consortium has created an organization on GitHub, named Canopies-H2020. This allows all partners to create repositories and share code both privately and publicly their developed software. The researchers and developers of consortium partners will receive an invitation to become members. All members of this Github organization will be divided into teams, based on topic that they will be working on. A member can be a part of as many teams as needed.

The teams created on Github are the following:

- agronomic_perception: team of developers working on agronomic vision.
- hri : team of developers working on HRI.
- manipulator: will include the packages required for the operation of the dual arm prototype as well as development of relevant software packages created by the partners.
- mobile_base: will include the packages required for the operation of the mobile base as well as development of relevant software packages for control, navigation, etc. created by the partners.
- multi_robot: will be used by the developers for multi-robot coordination related software packages.
- task_planning: will be used by the developers for task planning related software packages.
- virtual_reality: will be used to distribute the simulation and virtual reality environments.

All members will have access to edit the repositories assigned to their own teams, but they will only have the option to read, use and discuss other team's repositories as a standard setting.

Two persons from the consortium has been made administrators of the organization page. They will be ensuring that the structure of the teams and repositories is kept as designed. They will also be inviting new members and setup the correct access level. Even though all members can create repositories, the administrators will be in charge of assigning the repositories to the correct teams to avoid potential clutter.

2.7.3. Software integration

We will integrate the developed software components on the appropriate on-board computers based on specification such as software dependencies, criticality and deployment method. As an example, software deploying novel deep learning based techniques will be integrated to a GPU based computer or embedded platforms with deep learning optimization (Nvidia embedded platforms).

By splitting software components into self-contained packages, as well as, distributing them on different hardware platforms, the most critical components can be run continuously while components (including hardware and sensor interfaces) that are under active development can be updated without issues.

Some software components (e.g. legacy code) might be incompatible with the hardware and software architecture chosen for the robot system (i.e. x86, Ubuntu 20.04, ROS Noetic) or have conflicting dependencies with other components (e.g. requiring different version of the same library).

Therefore, for some components it will be a necessity to encapsulate them in docker containers, which provide isolation mechanisms that allow these compatibility issues to be handled, both in terms of OS and ROS versions as well as bundling all their own dependencies.

4. Key Performance Indices (KPIs) definition

Since the report will be updated in a regular basis the Key Performance Indices (KPIs) are only representing the currently identified and anticipated challenges.

For the first period of the project, we include metrics for measuring the robustness and effectiveness of the prototype and custom solutions. In this way, we expect to indicate the performance of the robotic prototypes, as well as our abilities to identify and design systems that will cover the aforementioned specifications.

Table 4: Key performance Indices for the current period

Label	Sub-system	KPIs title	Description	Target
KP1.1	Mobile base	GNSS interference	Placement of all components conflicting with the GNSS signal thus providing a robust signal strength.	Strength of signal at 70%
KP1.2	Mobile base	LIDAR placement	Placement of LIDARs that provides a full coverage around the robot without any obstruction in the FOV.	Full 360 degree coverage
KP1.3	Mobile base	Autonomy of sensor operation	Duration of sensor uptime while the mobile base is use, based on power consumption.	1,5 hours
KP1.4	Mobile base	Minimum bandwidth for data transfer	Required speeds of the wired Ethernet communications.	1Gbit/s
KP1.5	Dual arm	Horizontal reachability	The maximum height of arm reachability where the end effector can perform a cut	2 meters
KP1.6	Dual arm	Vertical reachability	The maximum length of arm reachability where the end effector can reach the boxes	1 meter
KP1.7	Dual arm	Power consumption	Minimum uptime of the dual arm due to power consumption.	2 hours
KP1.8	Agronomic vision	RGB information FoV	Field of View of the monocular RGB imaging sensors, considering the combination of all imaging sensors	min 65° H, 40°V
KP1.9	Agronomic vision	Depth information FoV	The FOV of either a stereo camera, RGB-D camera or a combination.	min 70°
KP1.10	Agronomic vision	Data acquisition	The number of images captured in case of continuous acquisition while the mobile base is moving.	min 5 picture per second
KP1.11	BEM	Power consumption	Minimum uptime of the BEM due to power consumption.	1,5 hours

KP1.12	BEM	Number of boxes on the farming robot	Minimum acceptable number of boxes on the farming robot	min 2
KP1.13	BEM	Number of boxes on the logistics robot	Minimum acceptable number of boxes on the logistics robot	min 4
KP1.14	Safety	Number of safety solutions	Number of the safety solutions implemented on the robot prototypes	3 safety solutions

In later versions of the document, i.e., after the results of periodic testing, the KPIs will be revised appropriately to reflect the expected performance level.