ROBS4CROPS

D5.4 Proven integrated autonomous farming operation system (2)

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Abstract:	The demonstrator deliverable describes and illustrates the current state of the actual working combinations of coordination software, vehicles and implements to be used in the four different large scale pilots of the project. This is the second version showing results of the factory and site acceptance tests of the Minimum Viable Product number (MVP) 2. The report also includes some test results from MVP1 that have not been reported earlier. The status for each pilot is reported and current bottlenecks and shortcomings are identified and summarized in additional tasks. A dedicated section is showing test results of the current functionality of the farming controller. It can be concluded that the practical integration of hardware and software into a viable product with many partners involved at different locations is a complex operation. Specifically the retrofitting of the tractors for autonomous driving is seriously delayed. Workarounds have been found for each of these issues. Therefore each LSP will be able to start field operations.

Document Revision History			
Date	**Version**	**Author/Contributor/ Reviewer**	**Summary of main changes**
29 March 2023	1	Jochen Hemming (WR)	Initial version

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RE	Restricted to a group specified by the consortium (including the EC Services)	No
CO	Confidential, only for members of the consortium (including the EC)	No

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ECU	Electronic Control Unit
FAT	Factory Acceptance Test
FC	Farming Controller
FMIS	Farm Management Information System
GNSS	Global Navigation Satellite System
IBBC	ISOBUS breakout connector
LIDAR	light detection and ranging
RTK	Real Time Kinematic positioning
MVP	Minimum Viable Product
LSP	Large Scale Pilot
PU	Perception Unit (for intelligent sprayer)
R4C	Robs4Crops project
TIM	Tractor implement management
SAT	Site Acceptance Test
VT	Virtual Terminal (a VT is a physical display that provides the user interface for interaction with the devices on an ISOBUS system)

1 Introduction

This demonstrator deliverable is the second version in a series of three that describes the actual working combinations of coordination software, vehicles and implements to be used in the large scale pilots (LSPs) as a Minimum Viable Product (MVP). This document specifically targets the MVP2 to be used in crop growth season 2023 and also includes some test results from MVP1, crop growth season 2022, that have not been part of D5.2 Proven integrated autonomous farming operation system 1.

This deliverable contributes to the project milestone MS24: Tests for MVP2 completed. This milestone is due in M27 (March 2023).

The earlier defined high level specification of requirements for the MVP2 are listed in Table 1.

Table 1. Updated specification of requirements for the different MVP based on table (from D5.1)

	MVP1 (M12)	MVP2 (M24)	MVP3 (M36)
Smart Implements	Field ready implements that are able to detect a limited number of anomalous conditions Status communication via ISOBUS Displays information on ISOBUS terminal	**Simple crop perception & selective application** **Tractor-Implement Management (TIM) implementation**	Advanced crop perception & selective application. Standardization and compatibility with future TIM versions
Autonomous Vehicles	Autonomous navigation on the field using robot manufacturers solutions	**Conventional tractor operates autonomously via retrofitting hardware and software** **Obstacle detection and circumnavigation**	Large-scale autonomous navigation system
Farming Controller	Digital World Model is updated with information from vehicle and implement Farming controller receives and represents vehicle position and weeding/spraying performance data Farming controller can abort an ongoing mission.	**Task dispatching based on a list of tasks to be done, resources needed for each task, and conditions that must be satisfied for each task**	Scheduling and dispatching of tasks. Advanced level of response to unexpected conditions.

2 LSP 1 – France

2.1 Description

The French LSP, in the 2023 season will again focus on mechanical weeding in vineyards with the CEOL robot. For the MVP2, hall effect sensors to detect the spinning metals of the implement are installed on the weeding implement to monitor whether the implement is working correctly. For MVP2 an improved electrical cabinet (the so called fuse box) was designed, built and integrated. Having worked extensively with the robot in 2022, the aim this year is to introduce the technology to more farmers.

2.2 Test results MVP1, growing season 2022

The FAT for MVP1 took place at AGC in Toulouse in November 2021. Mechanical and electrical connections were tested and passed validation. Data communication between the different modules were tested and found working. For more details see Deliverable 5.2, section 2.2. Shortly after the FAT, the system was transported to TER where further integration and site acceptance tests were performed. As described in more detail in Deliverable 5.3 the electronics cabinet was mounted on the robot between the robot and the implement. First tests running the robot in the vineyard caused the box to come loose as the mounting was not solid enough. It was proposed to the technical work packages to make the fuse box smaller and less heavy. In the end, middleware and analytics were not used in 2022, not only because of the mounting problems but also because the analytics sensor integration at the implement side and the correct cabling/connector between implement and autonomous vehicle was still pending. Nevertheless, the CEOL robot operated in most of the chosen plots several times in autonomous mode and experience in how to use the robot was gained.

Figure 1: Autonomous weeding with the CEOL robot in LSP1

2.3 Proven integration MVP2, growing season 2023

An integration and test meeting took place at TER in the week of February 13th 2023. Mechanical and electrical connections were tested and found to be working. The new fuse box fits the adapted frame. The frame is bolted to the weeder firmly, only the front leg couldn't be tightened. Sensors were mounted on the finger weeder elements (Figure 2). A test fit on the 'serrated disc' element has been done successfully. Only on the 'disc harrow' elements the sensor mounts do need modification. All sensors and cables have been tested and do work.

Sensor mounted on a "Kress-finger weeder" element}

Sensor mounted at 'serrated disc' element

Sensor mount with indication of new hole position (marks in circle), and sensor position (square).

Figure 2: Sensors mounted on the weeding implements

The operator screen or virtual terminal (VT) can be mounted on the CEOL robot, Figure 3. It is clearly visible and accessible by the operator of the robot. Please note that the VT is only necessary to put the robot in action at start of a task and to give the human operator/supervisor an additional possibility to monitor the status of the system/

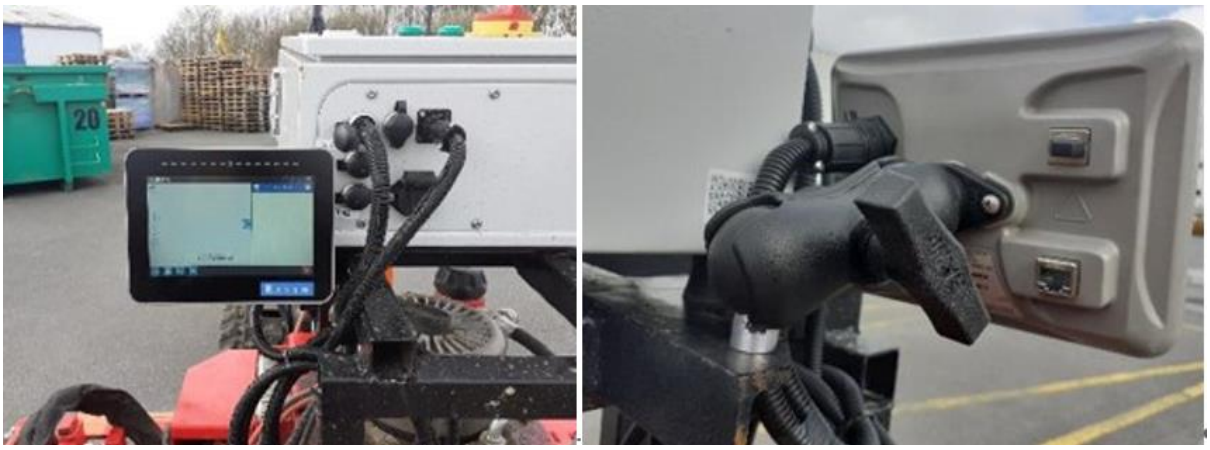

Figure 3: VT mounted on the CEOL robot

Data communication between the different modules was tested, but not all working. The communication between the middleware PC and FC works. ISOBUS/CAN communication between the middleware PC and CEOL works physically, but not all messages are defined and/or implemented correctly. Partners UHOH and AGC are working on these problems (March 2023). The missing messages have the implication that during the FAT the analytics/middleware PC could not request the CEOL to stop, which is a required functionality in the MVP.

The VT on the CEOL shows live status information and also the weeding quality. These values also are transmitted to the FC. Figure 4 shows a graph from data of the weeding quality that is logged by the FC. When a (simulated) blockage of the rotating elements occurs, the weeding quality drops.

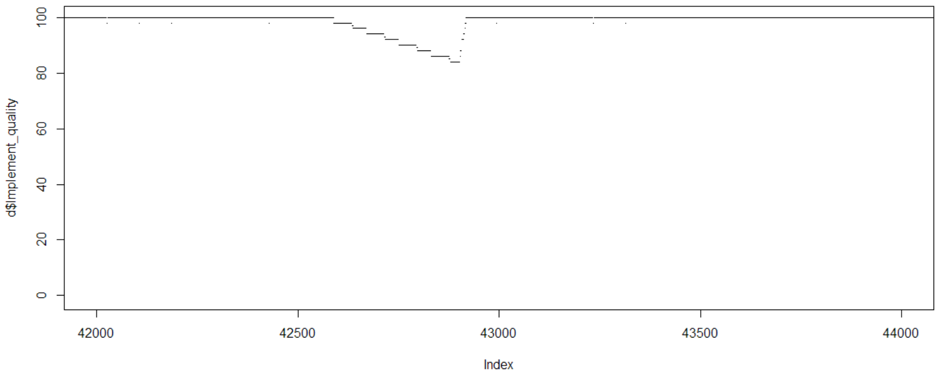

Figure 4: Weeding quality value (y-axis) over time (x-axis) calculated from data of the sensor mounted on the weeding implements. When a (simulated) blockage of the rotating elements occur the weeding quality drops.

A SAT was held at a vineyard at February 14th 2023. A route plan for the robot was made. When starting the plan issues with the GNSS accuracy required restarting the robot and GNSS-system. The field trial ended before the robot entered the vine rows, because a roller of the robot's track system broke.

Figure 5: Broken front roller of one of the tracks of the CEOL robot

2.4 Additional tasks

One concern with the current MVP2 in LSP1 in France is the excessive vibration of the weeder. Although the fusebox is improved and strengthened compared to last year, it is not unlikely the vibrations might cause problems. Most heavy vibrations are caused by the rear end roller.

The full implementation of the TIM communication between implement (middleware PC) and robot (CEOL) is still work in progress. Only after implementation by UHOH and AGC, the implement can give recommended changes in for example speed or hitch position to the robot, based on the results of the weeding analytics.

The sensors on the discs of the weeder are in place and generate data, still the analytics software needs to be calibrated and finetuned before meaningful data can be extracted. Attention should be paid to the mounting of the rollers of the CEOL robot to prevent break-down of the robot.

3 LSP 2 - Greece

3.1 Description

In Greece the pilot field operations are on robotic spraying for table grapes on commercial farms of the PEGASUS farmers' cooperative. The 2023 season will start without the autonomous navigation for the tractor but with a manually driven tractor. As smart implement the same 3-point hitch lifted ASM 200 Sprayer (TEY) as 2022 will be used, again equipped with the Perception Unit (PU), a camera-based analytics module (AUA). The initial aim is to have the perception system, the sprayer, and communication with the Farming Controller operational.

Before autonomous navigation will be implemented on the tractor, autonomous navigation will be implemented on the CAROB robot. The CAROB is a modified (more powerful/larger) version of the CEOL robot from AGC that is able to carry the smart sprayer. The CAROB robot is currently under construction and will be delivered to Greece, together with the LIDAR-localization software, in April or May 2023. Due to the metal supports of the vineyard that inhibit the GNSS signal, autonomous navigation will not be GNSS-based, but LIDAR-based, developed by partner EUT. The CAROB should be able to work according to a plan, drive straight lines, perform turns, perform mission planning, run several rows, stop on faulty conditions.

Later in the season it is planned to also install an autonomous retrofit kit on the tractor in Greece that is currently tested for the Spanish pilot.

3.2 Test results MVP1, growing season 2022

The Greek pilot uses very much the same components/modules that are also used and tested in the LSP3 (Spanish pilot). As described in more detail in D5.2 and D5.3 it took more time than expected to get the R4C tractor for the Greek pilot purchased. In first instance field operations in 2022 were carried out with an alternative, manually steered tractor with the sprayer from TEY (Figure 6). The sprayer was controlled by the perception unit (Figure 7). Other than originally planned and described in D5.2, the CAROB robot was not yet available as MVP1 in the 2022 season of the Greek pilot.

Figure 6: Tractor with TEYME ASM 200 sprayer at the pilot site in Greece

Figure 7: Crop perception unit mounted on R4C tractor

3.3 Proven integration MVP2, growing season 2023

In late November 2022 the sprayer, the ISOBUS terminal, and a range of sensors that will be used for navigation in MVP2 (Figure 8), were successfully integrated and demonstrated in Kiato, Greece.

Figure 8: Sensors for navigation unit mounted on R4C tractor

A first SAT test meeting took place on February 14th 2023, at the grape field next to the Pegasus warehouse in Moulki, Greece. The field and a part of the warehouse are visible on the image below, Figure 9. Note that in February, the grape field was not green, as there were no leaves at all. Therefore the perception unit could not be tested on the grapes, but was tested on olive trees at the boundaries of the field (Figure 10). Present at testing: Giannis Avgoustakis and Loukas Athanasakos from AUA, Thanos Dritsopoulos (PEG), Nikos, a Pegasus member farmer and Eva de Jonge (WR).

During the first spraying in March, it is likely that the leaves are too small to be detected by the perception unit. It might be necessary to use manual mode and use the perception unit only in a later stage, when the leaves have grown.

Figure 9: Test field next to Pegasus warehouse in Moulki, Greece

Because of the metal structures between the trees, localization in MVP2 won't be GNSS-based; the tractor will be driven manually. For the same reason, the speed that is needed for the sprayer dosage does not always work via the AGC box-GNSS. It worked during this test. In other cases, the following applies:

1. If the PU does not receive an ISOBUS speed message when it starts, it uses a predefined "simulated" speed.
2. If and when the PU starts receiving ISOBUS speed messages, that overrides the simulated speed.
3. If the ISOBUS speed messages stop, the PU uses the latest speed value it has received.

Both sides of the perception unit were tested by driving past the olive trees at the sides of the field (they had leaves). The perception unit, the AGC box (GNSS) and the sprayer worked perfectly on the olive trees. They started and stopped spraying at the right moment.

The manual mode on the sprayer worked fine and has passed the validation.

The AGC-controlbox heartbeat signal was present the whole time and the GNSS worked during the whole test.

The perception unit, the communication with the AGC box and with the FC were tested, everything worked fine. The FC was able to collect the data from the tractor (GNSS, Speed). The sprayer and perception unit data is not directly sent to FC, but via the Middleware PC (Pokini, UHOH). The data from the perception unit was not yet received by the FC, this topic is under investigation at the time writing this report (March 2023).

Figure 10: Perception unit, AGC box and sprayer worked well on olive trees

The ISOBUS cables are protected now, but some AUA power cables and electronics were not well protected against water and field circumstances during the SAT, Figure 11. This issue has been fixed in the meantime as shown in Figure 12.

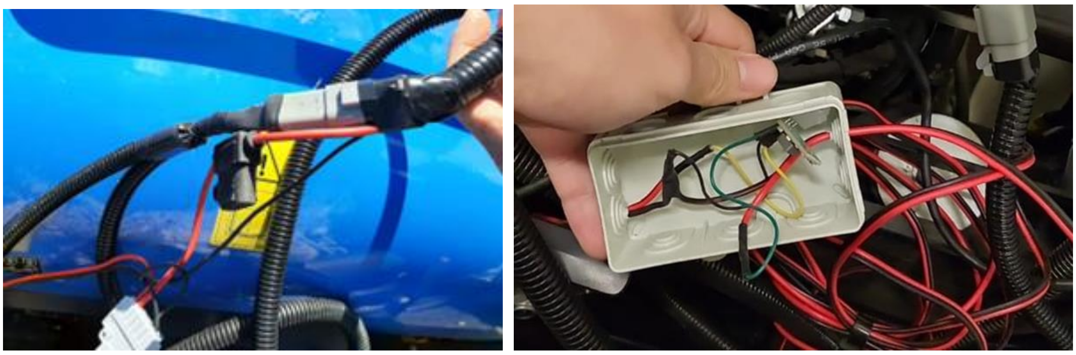

Figure 11: Power cables and electronics were not well protected during SAT in February 2023

Figure 12: Better protection for cabling, March 2023

The VT terminal is still mounted with tie wraps, this should be replaced with a decent mounting system.

Figure 13: VT terminal is still mounted with tie wraps

Hood of the tractor is loose because of the cabling going under and not trough.

Figure 14: Hood of the tractor is loose

Important remarks

1. After restarting the tractor, always switch the two power switches off and back on, to reinitialize the whole system (the black switch next to the battery and the red switch next to the seat. This takes a little while as the middleware PC needs to restart).
2. It is important to NEVER switch off/on sprayer by activating/deactivating the hydraulics at the end/beginning of the rows. Hydraulics should remain powered at all time. In November the operator switched off / on the hydraulics on the beginning/end of the rows and this can cause very serious damage to the sprayer. This issue was resolved in March 2023 by using hydraulic extension hoses to connect the implement to hydraulic outlets of the tractor that can remain on without specific operator action.

3.4 Additional tasks

- Getting the implement data to the FC via the middleware is still work in progress.
- Make sure the hydraulics for the sprayer are connected in such a way that they work as they should during operation. To eliminate the risk of operators doing damage to the sprayer (see point 2 above).
- Fix cabling under hood of tractor, so that it doesn't move. Drill a hole.
- Install a decent mounting for the VT terminal.

4 LSP 3 – Spain

4.1 Description

The LSP3 is apple orchard spraying with a tractor in Spain. The aim for season 2023 is to have the autonomous retrofit kit for the tractor fully operational. Because the GNSS signal is not reliable in the orchard, specifically under the plastic nets with metal supports, navigation will be based on the same LIDAR-based localization developed by EUT that will be used in the Greek LSP 2.

The retrofitted tractor should be able to work according to a plan, drive straight lines, do turns, stop on faulty conditions. As last year, the sprayer should work in combination with perception unit.

4.2 Test results MVP1, growing season 2022

In addition what was already earlier described in D5.2 a FAT was performed at the end of April 2022 at the location of TEY in Lleida (Spain).

During this FAT it was tested and confirmed that:

- Sprayer and hydraulic hoses can be attached & towed by the tractor.
- The perception unit including cameras can be mounted on the correct position on tractor.
- VT terminal (brand ANEDO) can be mounted inside the tractor and can be connected to the ISOBUS and powered.
- AGC box calculates the GNSS position when system is in open sky.
- Integrated system was tested outdoors and complete system power-up was established. Perception unit currently starts with manual commands, but soon it will be configured for automatic start upon powering-up.
- Local data logging of all values is working.
- Internet connectivity: A 4-G internet module provided the necessary connectivity for the system. Further discussions are ongoing in order to select a more universal internet hardware solution to accommodate also EUT needs for autonomous navigation.
- During the FAT it could not be tested that the FC receives, represents and records vehicle position and sprayer status.

End of June 2022 the sprayer was shipped to the pilot location. The SAT was carried out in the farm "El Cortal Gran" in Carretera Sant Martí d'Empúries, 17470 Sant Pere Pescador, Girona. This farm belongs to SERRATER, which has several fields in l'Empordà, Girona. On top of what was achieved at the FAT in the SAT it was proven that:

- Internet connectivity was active all time in the field where the pilots will be done, On the facilities of Serrater, we have experienced connection outages sometimes.
- When operating the system in the orchard under rows with a plastic net GNSS data loss occurred occasionally. This will be critical when GNSS is essential for autonomous navigation.
- Data from the pilot system could be sent to the FC.
- Sensors for autonomous navigation were mounted on the tractor (Figure 15) and sensor data was collected.

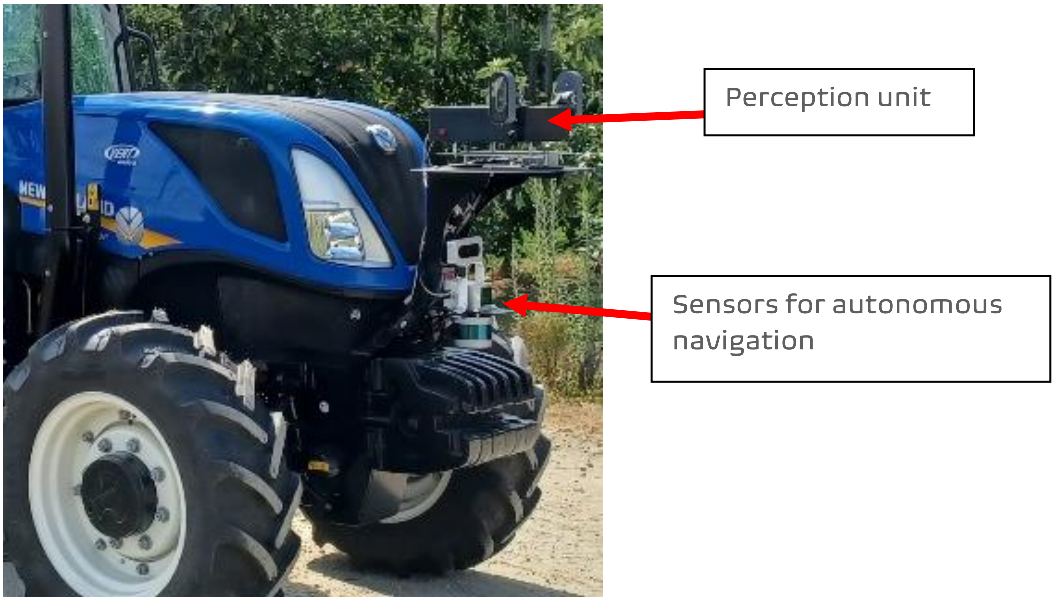

Figure 15: Sensors for crop perception and navigation mounted on R4C tractor of the LSP3 (MVP1)

More detailed results and feedback from the 2022 season of the Spanish LSP can be found in D5.3.

4.3 Proven integration MVP2, growing season 2023

The realization and integration of all needed modules to be able to perform autonomous navigation and operation with the retrofitted tractor experience some significant delays. At the moment of writing this document, March 2023, the autonomous retrofit kit for the tractor is not yet fully operational.

As the AGCBox from AGC is used for GNSS and low-level control of the tractor it was decided to perform the FAT at the premises of AGC in Toulouse. This FAT took place mid of February 2023. Lesson learnt from last season was that the GNSS signal is not reliable in the orchard, therefore it was decided that autonomous navigation will be based on LIDAR, speed encoders and angle sensors on the tractor in case no GNSS information is available.

During the FAT It was proven that both AGCBox and the Navigation On Board Unit (NOBU) developed by EUT, the Perception Unit from AUA, and the VT are correctly installed. The AGCBox was mounted above the cabin (see Figure 16). The NOBU was placed at its dedicated place behind the driver's seat. It was confirmed that it has proper communication with the AGCBox and it was powered on at tractor's ignition. Encoders and angle sensors were not yet installed on the tractor because they have not yet been received due to unexpected long delivery times. During the FAT it could also be confirmed that EUT's and AGC's applications were communicating properly to drive the tractor around. So far this could only be tested in open-loop. Basically the AGCBox was given some linear and angular velocity, from the NOBU, and the AGCBox was giving commands to the gas actuator and the steering wheel actuator of the tractor to drive the tractor. Internet connectivity of the full system and VPN communication among the different modules was proven to work.

Figure 16: Tractor for Spanish pilot during MVP2 FAT, February 2023

4.4 Additional tasks

Before MVP2 is fully functional additional tasks must be carried out. At the time writing this document theses task are ongoing. Some of the tasks are postponed until the tractor is shipped from AGC to the pilot site location at SER in Spain.

- Install and test wheel encoders on the tractor.
- Install and test angle encoders on the tractor.
- Add additional sensors for autonomous navigation from EUT
- Test LIDAR-based localization and navigation
- Test if straight lines can be driven autonomously
- Test if turns can be driven autonomously
- Test if tractor stops on faulty conditions
- Verify that FC receives, represents and records vehicle position.
- Test if system can receive and execute a plan from the FC

5 LSP 4 – The Netherlands

5.1 Description

In the 2023 season the Dutch LSP will be about seeding and weeding in sugar beets using the same Robotti and mechanical weeder as in MVP1. In MVP2 the camera-based weeding quality and fault detection algorithm should work, and upon an error the robot should stop. Narrow tires that fit between the sugar beet rows will be installed on the Robotti once seeding is finished. Other than during the MVP1 the system should work neatly also on the headland and field corners. For MVP2 the operator should be able to set the minimal weeding quality on the VT.

5.2 Test results MVP1, growing season 2022

In addition what was already described in D5.2 a FAT for the Dutch pilot was performed at the end of March2022. At that point in time several issues where discovered, such as that the cameras to collect data for the weeding analytics module where not yet working and that also no messages were present on the CAN bus. In the beginning of May 2022, a SAT was conducted. The message issue on the CAN bus was solved by then, but still no cameras were present. Cameras were added only later in the season when the second experiment (weeding in sugar beets) started.

More detailed results and feedback from the 2022 season of the Dutch LSP can be found in D5.3.

5.3 Proven integration MVP2, growing season 2023

For the MVP2 of the Dutch pilot (LSP 4) two test events took place so far, the first one on 3rd of February 2023 at the location of the experimental farm of WR in Lelystad in the Netherlands and the second one on 23rd of February 2023 at ABE test field in Dronten, the Netherlands. During these tests it was confirmed that:

- the fuse box is securely mounted onto the Robotti.
- the cameras for analytics are mounted on the correct position on the implement.
- the analytics can access the cameras and acquire images through Ethernet.
- the VT can be mounted onto the Robotti, visible and accessible for the operator.
- The weeder implement is mounted correctly including side shift module.
- fuse box receives power from the ISOBUS connection to the Robotti
- that the Robotti calculates its position and has a RTK fix.
- it is possible to log into Robotti Wi-Fi access point with a tablet or laptop. Is it possible to reach the internet with this connection
- the Robotti can execute a pre-defined mission using the Agrointelli software.
- that hydraulic row-following side shift module on the weeder is working correctly
- the FC receives and records vehicle position and speed.
- the FC and the VT receive weeding performance data (so far simulated data only)
- Robotti can also work neatly in field corners. Corners are much better reached than last year.

The photos below show some details of the system during the FAT test.

During the test events some open issues were found. These are listed in the next section "additional tasks".

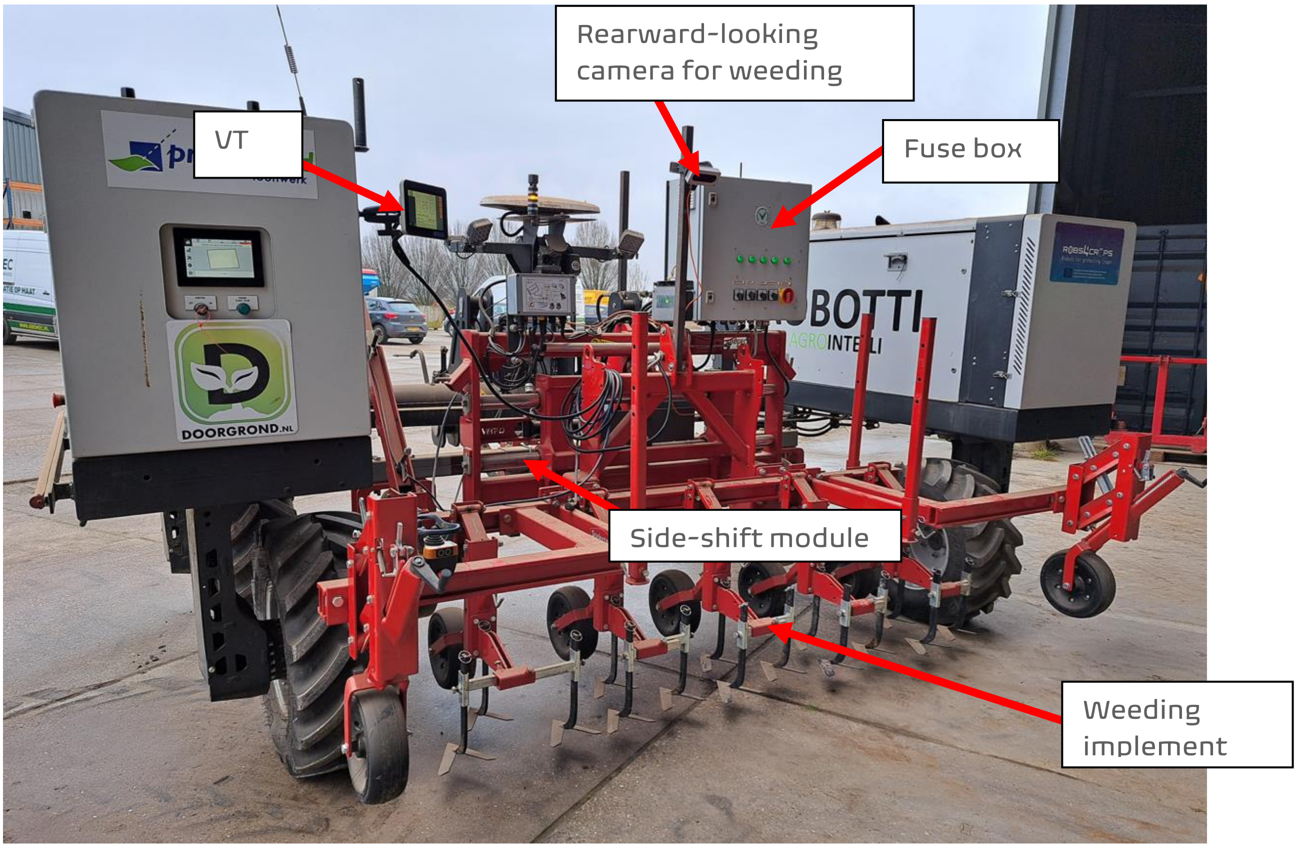

Figure 17: Robotti with weeding implement during MVP2 FAT, February 2023

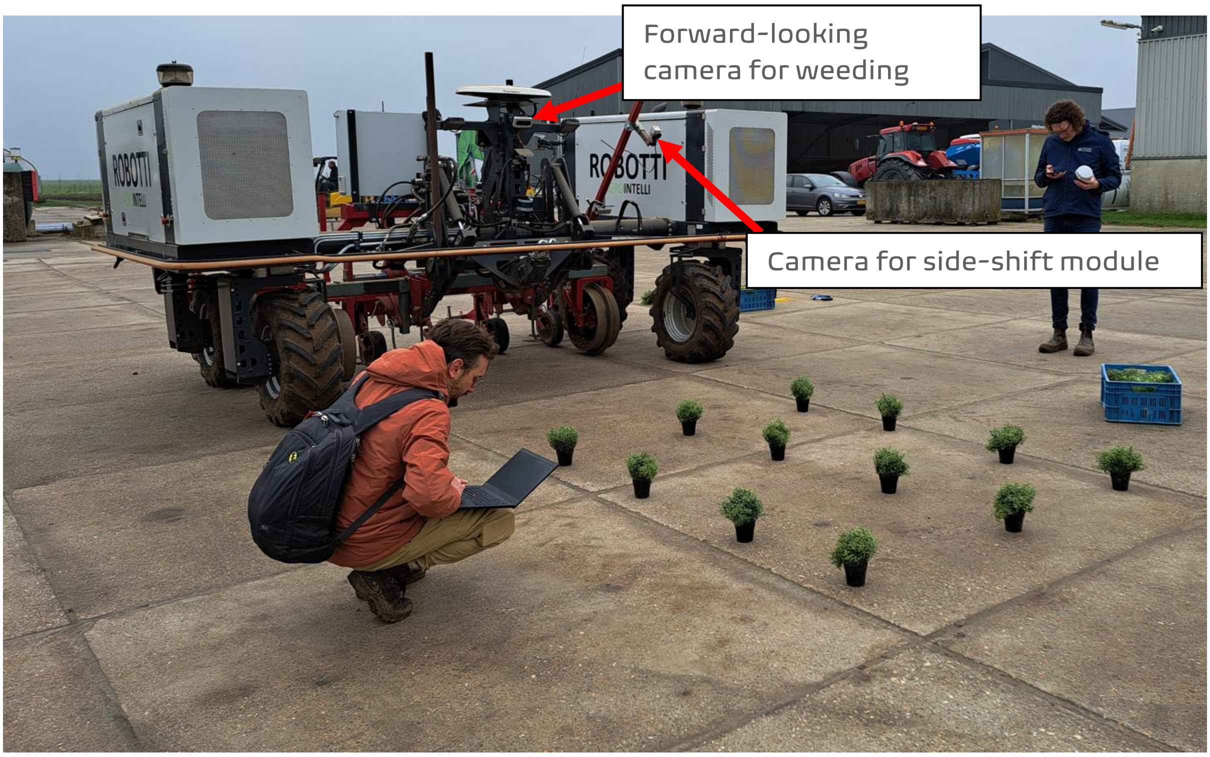

Figure 18: Testing of weeding analytics with simulated plants during FAT, February 2023

Figure 19: VT mounted on the Robotti showing live values of speed and weeding quality

5.4 Additional tasks

- The analytics of the weeding algorithm is still work in progress and is not yet fully implemented on the system. Therefore the user can also not yet set a target value for minimum weeding quality in the VT.
- A (simulated) stop signal from the weeding analytics is displayed correctly in VT, but during the FAT the Robotti did not respond to this signal. It was found that due to recent changes in the middleware –to implement TIM- the way of communicating the stop signal has changed with respect to MVP1. At the time of writing this document (March 2023) this issue should have been solved.
- Vehicle speed values transmitted to and logged by the FC contained sporadically very high and unreasonable values. AGI investigated that issue. After the next software update of the Robotti the issue should be solved.

6 Farming Controller and Digital World Model

6.1 Description

Whereas the role of the FC for the MVP1 of all pilots was mainly to collect and store data from the different systems in the pilots, the FC in MVP2 will have the ability to control a real robot in a real field. More specifically the FC will:

- Make an initial plan for the retrofit tractor(s), suggesting speed, acceleration and waypoints order.
- The robot starts to follow the path. While following the path, the robot continuously informs the FC about its position, speed, and whatever else it measures.
- Based on dynamic circumstances, replan the above path.
- During a mission start a new mission based on farming controller command, I.e. simulate an unexpected rain
- FC controls and demonstrates the above with a real robot in a real field.
- The digital world model is updated with information from a real robot and implement in a real field implement

- The Human Machine Interface (HMI) of the FC and the visualization capabilities will be further developed. This will allow the user to simulate for example "unexpected events" by using buttons in the HMI.

Before implementing this on the retrofitted tractors in the Spanish pilot and eventually also the CAROB in the Greek pilot WR will implement and test the new FC functionality in close interaction with LMS on a small size unmanned ground vehicle, the Husky robot[1]. This field robotics platform supports ROS from its factory settings and is therefore very suitable for this test. The results of this test are described below in section 6.3.

6.2 Farming controller test results MVP1

The tested functionality of FC in MVP1 was described already in in D5.2. Moreover, the functionality described above for MVP2 was in 2022 already been tested and demonstrated in a simulation environment.

6.3 Farming controller proven functionality MVP2

To speed up testing and implementation the added functionality of the FC as described above was first tested outside the LSPs.

In March 2023 it was proven that:

- A small size unmanned ground vehicle (The Husky) can connect with the remote FC (via ROS) using a mobile 4G internet connection and VPN.
- The Husky sends speed and GNNS data to the FC, the FC logs this data
- The Husky (located at WR in the Netherlands) initiates interaction with FC (located at LMS in Greece) and receives a single goal position or a series of goal positions to follow (a path).
- The Husky navigates to the goal(s) and sends feedback to the FC.
- The Husky can be pre-empted and sent to new/updated goal.

Figure 20: Testing the new FC functionality with a Husky robot at the premises of WR

[1] https://clearpathrobotics.com/husky-unmanned-ground-vehicle-robot/

6.4 Additional tasks

The above effort will lead to a refinement of the communication protocol between the FC and a robot. Later in the year it is the goal to control the retrofitted tractor and/or the CAROB in the same way.

7 Conclusions

This demonstrator deliverable describes and illustrates the current state of the actual working combinations of coordination software, vehicles and implements to be used in the four different large scale pilots of the project. This is the second version showing the status of the Minimum Viable Product number 2.

It can be concluded that the practical integration of hardware and software into a viable product with many partners involved at different locations is a complex operation. For all LSPs current delays, bottlenecks and shortcomings have been identified and summarized in additional tasks. This confirms the importance of WP5 to perform tests as early as possible such that there is still time to solve the issues before field operations start.

For some LSPs the delays have more implications for the 2023 season than for others. Specifically the retrofitting of the tractors for autonomous driving in the Greek and Spanish pilot is seriously delayed. Activities for Tractor-Implement Management (TIM) are still in full progress and could therefore not yet be tested.

Workarounds have been found for each of these issues. Therefore each LSP will be able to start field operations with their combination of vehicle and smart implement.

8 References

Robs4Crops Deliverable 5.2 (2021): Proven integrated autonomous farming operation system.

Robs4Crops Deliverable 5.3 (2022): Feedback to pilot community and manufacturers on the capabilities and limitations of the delivered integrated solution of implements, vehicles and supervision software (1).