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ROBS4CROPS

D5.2 Proven integrated autonomous farming operation system

robs4crops.eu

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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 first version showing the status of the Minimum Viable Product number 1. All pilots have a proven integration and the status for each is reported and current bottlenecks and shortcomings are identified and summarized in additional tasks. A dedicated section is showing the current functionality of the digital world model of the farming controller.

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AMQP	Advanced Message Queuing Protocol
ECU	Electronic Control Unit
FC	Farming Controller
FMIS	Farm Management Information System
GNSS	Global Navigation Satellite System
RTK	Real Time Kinematic positioning
MVP	Minimum Viable Product
LSP	Large Scale Pilot
R4C	Robs4Crops project

1 Introduction

This deliverable 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). There will be three consecutive versions of this deliverable, each version will be delivered always a few months ahead of the start of the season of the LSPs. In such a way there is still time to identify and correct missing functionality or to malfunction of the modules before the actual LSP starts. This deliverable will thus have updates on M24 and M36 of the project.

This is the first version (M12) of the deliverable, showing the status of the integrated autonomous farming operation as defined in the MVP1 as depicted in Table 1 (for a more detailed description of the MVPs see also deliverable 5.1). This deliverable contributes to the project milestone MS14: Tests for MVP1 completed. This milestone is due in M15 (March 2022).

Table 1. Definition of the MVP1 (from D5.1)

	MVP1 (M12)
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
Autonomous Vehicles	Autonomous navigation on the field using robot manufacturers solutions
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.

2 LSP 1 – France

2.1 Description

The MVP1 for the French LSP is mechanical weeding in the vineyard with CEOL robot. The following components are needed to perform the LSP. The responsible project partner for providing the component is listed in brackets.

- Smart Implement: Mechanical weeding implement with tines (TER). The implement has extensions on both sides which allow weeding between the vines. This is achieved with a sub-surface blade to cut the weeds that sweeps out from the implement between vines. The blade is retracted when a feeler bar in front of the blade touches a vine. The blade is operated by hydraulic power. The implement is equipped with one or more cameras and analytics software to detect the weeding quality and anomalous conditions (WR).

- Autonomous vehicle: CEOL with the following features: Physical connection: 3-point hitch. Electrical connection: ISOBUS. Software connection: internet router (Wi-Fi and or cable) that is connected to the internet via 3/4G (AGC)
- Farming controller: Network based FC as developed in the R4C project (LMS)

2.2 Proven integration

During an integration meeting at AGC in Toulouse in November 2021 the modules needed for the MVP1 of this LSP were integrated. Mechanical and electrical connections were tested and found to be working. Data communication between the different modules were tested and found working.

Figure 1 shows the mechanical weeding implement that will be used. The implement has tines and extensions on both sides which allow weeding between the vines. This is achieved with a sub-surface blade to cut the weeds that sweeps out from the implement between vines. The blade is retracted when a feeler bar in front of the blade touches a vine. The blade is operated by hydraulic power. Figure 2 shows how the electronic box containing the middleware and weeding analytics industrial PC and electrical connections will be mounted on the implement.

Figure 1: Weeding implement for the LSP in France

Figure 2: Electric cabinet with middleware and analytics hardware mounted on implement

The cameras used for the weeder analytics module that observe the weeding operation will be from the Basler ace 2 series[1] (Figure 3) and will be connected by USB cable to the analytics hardware. It was proven that the weeder analytics module can communicate using CAN messages with the middleware. As the current development of the image analysis based weeder analytics module is still work in progress, the communication was verified by sending software generated messages using a test GUI of the analytics module (Figure 4). Weeding status messages show up on a virtual ISOBUS terminal (Figure 5). Different scenarios/messages were simulated in the analytics module (e.g. error / no error) and show up on the terminal.

Figure 3: Cameras used by the analytics module in the LSP1 (Image source: https://www.sodavision.com/product/basler-ace-2-series/)

[1] https://www.baslerweb.com/en/products/cameras/area-scan-cameras/ace2/

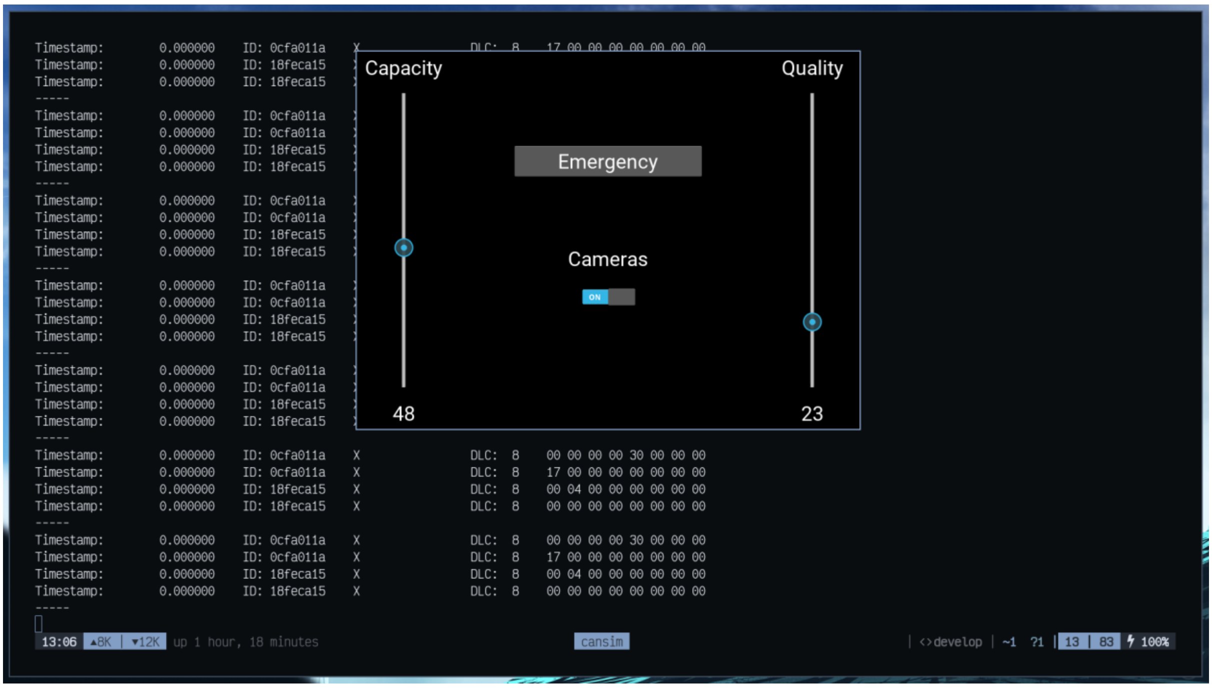

Figure 4: Screenshot of "ANALYTICS SIMULATOR" sending CAN messages to the middleware. The window in the centre of the screen has controls that can be used to simulate messages that the weeding implement sends to the vehicle.

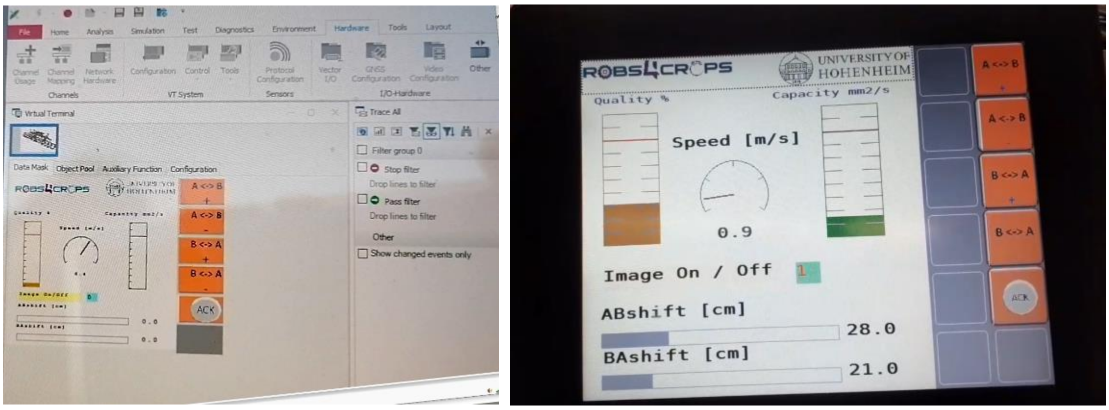

Figure 5: Virtual ISOBUS terminal showing information of the implement. Left image: software version of the virtual terminal in the middleware. Right image: photo of real virtual terminal hardware.

Figure 6 shows the CEOL that is used as autonomous vehicle in this LSP and in Figure 7 it is illustrated that the weeder implement can be attached to the CEOL and that the CEOL is capable of towing the implement (photo provided by AGC, from an earlier experiment).

Figure 6: CEOL autonomous vehicle

Figure 7: CEOL towing the weeding implement

in Figure 8 it is shown that middleware can communicate by means of CANopen messages with the CEOL, in the future this will be changed to full-fledged ISOBUS protocol. It was proven that the CEOL can receive commands from the implement (middleware) to abort an operation.

Figure 8: Demonstrating communication between implement (middleware) and CEOL.

Bidirectional communication between the FC and the CEOL have been proven using the Advanced Message Queuing Protocol (AMQP)[2]. In case the FC is cloud-based this will be done using a Virtual Private Network (VPN) connection for security reasons. In such way the FC will be able to receive and record data on and to send an abort mission command that is handled by the CEOL (work in progress). Communication between the FC and the analytics software was proven to work through the middleware using websockets (Analytics => (CAN) => Middleware => (websockets) => FC.

To define a new mission and for autonomous navigation the existing planning module of AGC will be used. This was tested and proven to work.

2.3 Additional tasks

It is work in progress to move the communication between the weeder implement and CEOL from CANopen to ISO11783 format, however, also by using CANopen the pilot can start as planned.

As described in deliverable 5.1 in section 2.1.6 and 2.1.10 it still needs to be verified in the field that the CEOL robot aborts a mission and stops in case the implement (analytics module) issues a critical failure condition on the CAN/ISOBUS. As this should be done by placing appropriate test objects in front of the analytics camera(s) a more advanced stage of the analytics module is required. This is still work in progress but to be expected to be possible when reaching in month 15 (March 2022) of the project milestone MS14: Tests for MVP1 completed.

[2] https://en.wikipedia.org/wiki/Advanced_Message_Queuing_Protocol

3 LSP 2 - Greece

3.1 Description

LSP2 will focus on robotic spraying for table grapes on commercial farms of the PEGASUS farmers' cooperative. The LSP will start in the spring of 2022. The MVP1 will use the bigger and more powerful CEOL, called CAROB, as autonomous vehicle and a 3-point hitch lifted ASM 200 sprayer from TEYME.

- Smart Implement: 3-point hitch lifted ASM 200 Sprayer (TEY) equipped with camera-based analytics module (AUA) that is able to detect diseases and adjusts spray volume (via ISOBUS).
- Autonomous vehicle: special modified (more powerful/larger) version of the CEOL robot, called CAROB (see deliverable 3.1 for a detailed description) that is able to lift and carry the sprayer. In the following referred to as the "CEOL/CAROB".
- Farming controller: Network based FC as developed in the R4C project (LMS)

3.2 Proven integration

During an integration at AGC in Toulouse in November 2021 the modules needed for this LSP were integrated. Mechanical and electrical connections were tested. Data communication between the different modules were verified.

At the moment the meeting took place the physical sprayer unit was still under construction. Figure 9 and Figure 10 show CAD drawings of the ASM200 sprayer. The full cable harness of the sprayer including the Electronic Control Unit (ECU) of the sprayer and the crop perception system was available and as such all electrical connections and communication protocols were integrated and tested. Figure 11 shows a photo of all combined components, this photo was taken during the integration meeting. On this photo the ISOBUS virtual terminal is showing status information of the crop perception system. Figure 12 shows the schematics of the sprayer cable harness.

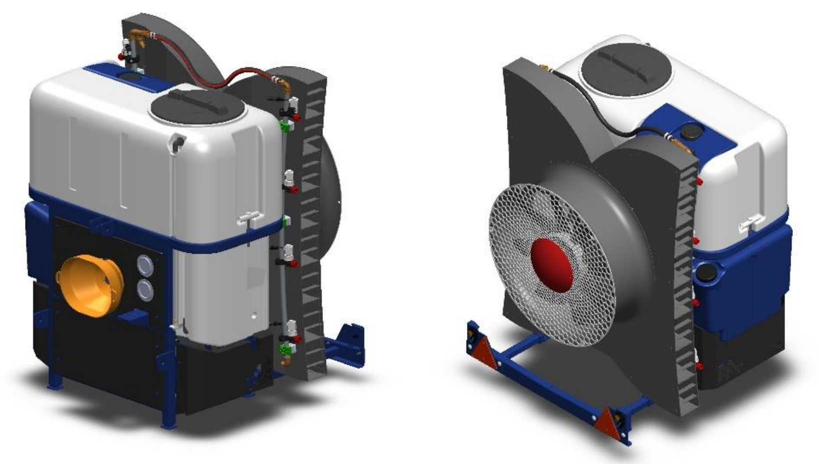

Figure 9: Drawings of the 3-hitch point lifted ASM 200 sprayer of TEYME

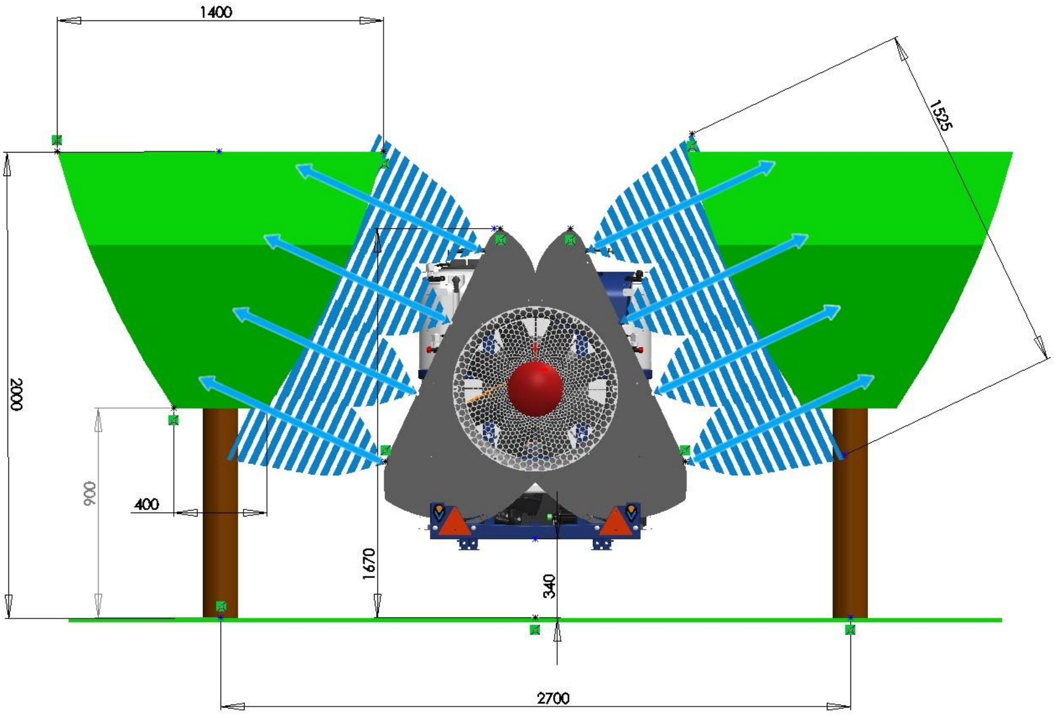

Figure 10: Illustration of the working principle of the ASM 200 sprayer of Teyme in the vineyard

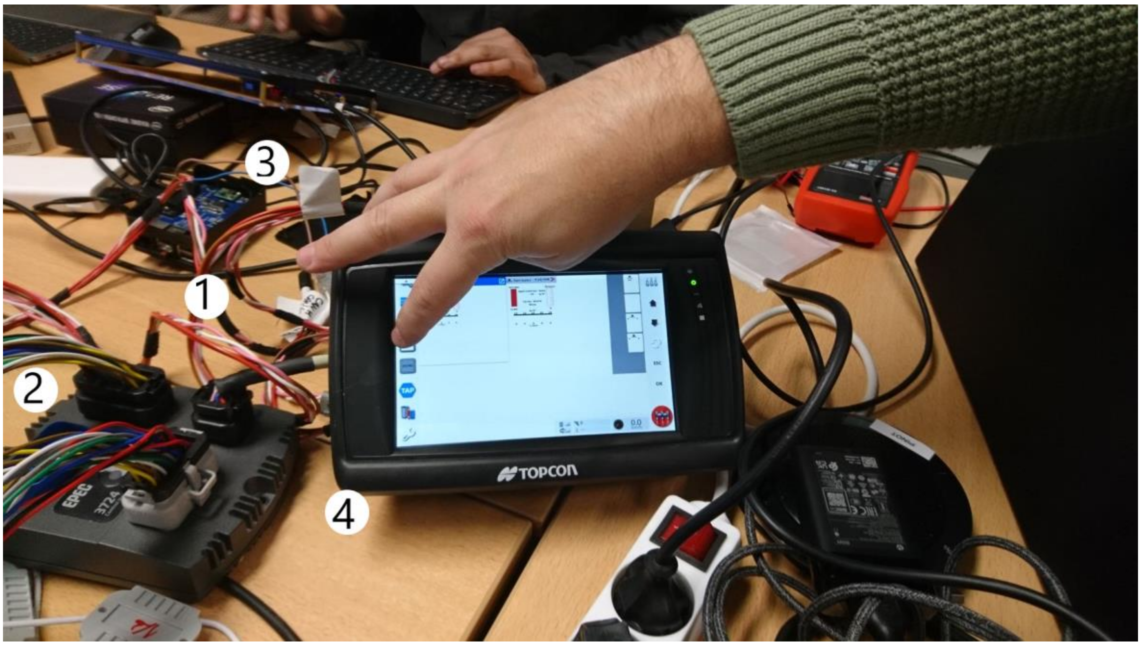

Figure 11: ISOBUS virtual terminal showing status information. 1 – Physical harness of the sprayer (Prototype version, but completely functional), 2- Sprayer ECU 3- Crop Perception module, 4- ISOBUS virtual terminal

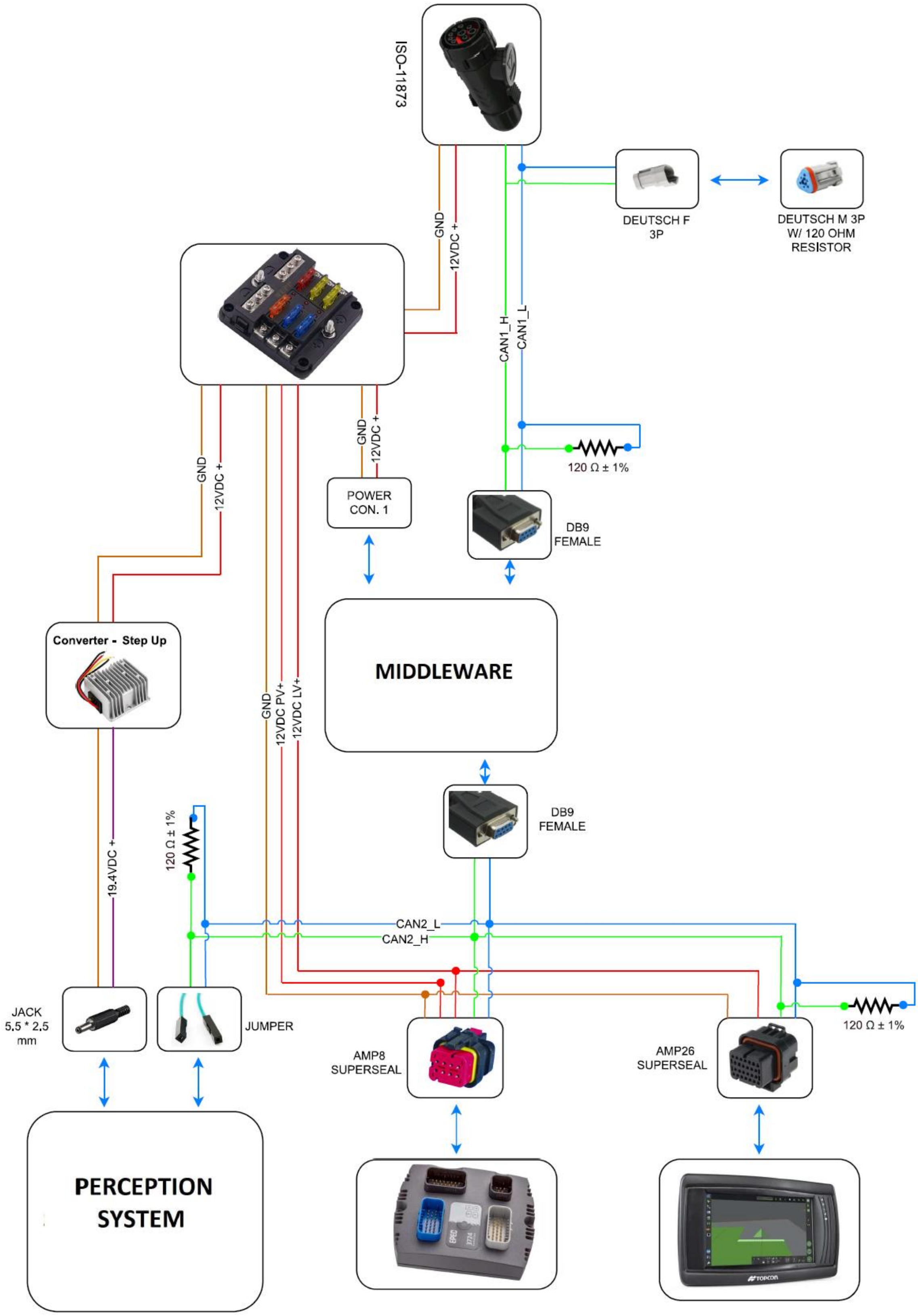

Figure 12: Schematics of the sprayer cable harness including the ECU of the sprayer, the crop perception system and the middleware

The perception module for this LSP consists of a NVIDIA Jetson embedded computer with a connected Intel RealSense combined colour and active stereo camera, RGB-D (Red-Green-blue and Depth) as displayed in Figure 13. An example image recorded with the perception module is shown in Figure 14. The module is ISOBUS-ready and was integrated with the TEYME sprayer ECU as shown in Figure 11. The main goal in the MVP1 is to test its AI capabilities at symptoms detection and tree/vine volume estimation. This information will be used for liquid and air volume modulation in real-time by the sprayer.

Figure 13: Perception module consisting out of a NVIDA Jetson embedded computer and Intel RealSense RGB-D camera.

Figure 14: Example pair of colour and depth image recorded with the perception module.

For LSP2 the autonomous vehicle is the CAROB from AGC. In contrast to the CEOL robot this robot is more powerful and is a modular with an adjustable width from 1.3 m to 1.6 m (Figure 15). Concerning control and communication the CAROB uses the same AGC-box and software that is also used in the CEOL.

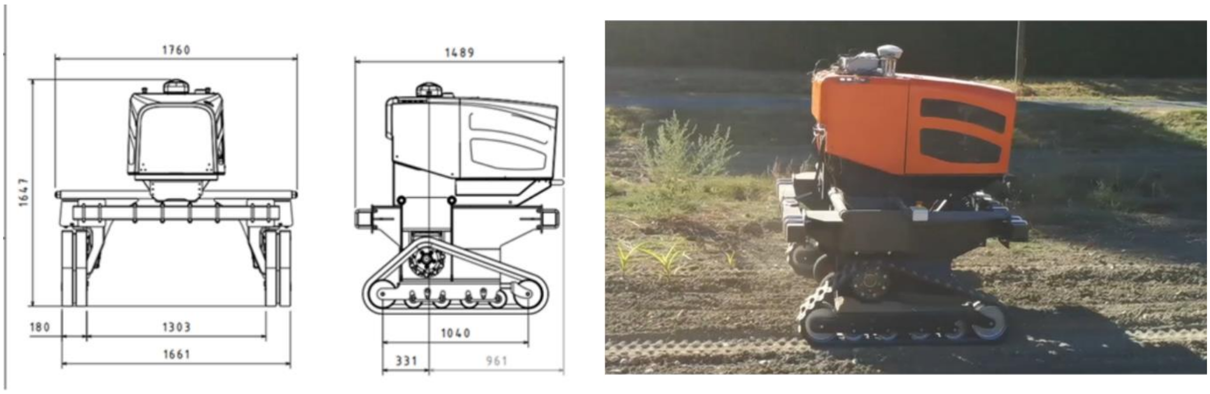

Figure 15. CEOL/CAROB robot from AGC (source: Figure 1 of D3.1)

Communication between implement (sprayer & crop perception) and CAROB/CEOL (AGC-box) can be done in two ways:

1. A separate middleware PC communicates with the sprayer and crop perception on the one side and with the AGC-box on the other side using ISOBUS and/or CANopen. The communication between CAROB/CEOL and the FC is done using the Advanced Message Queuing Protocol AMQP. Communication between the implement (sprayer & crop perception) and the FC is done using web sockets.
2. The AGC-box communicates via ISOBUS and/or CANopen directly with the implement (sprayer and crop perception). The AGC-box will send sprayer/perception data and vehicle status and will receive data (e.g. abort mission command) to and from the FC using AMQP.

Option 1 was already proven to work (see in the description of LSP1 and Figure 8 and Figure 11). For simplicity option 2 is preferred because no separate middleware (hardware & software) will be needed but at this stage of the development it is not clear if this option will be ready to use in the MVP1

To define a new mission and for autonomous navigation the existing planning module of AGC will be used. This was tested and proven to work.

3.3 Additional tasks

Once the construction of the ASM200 sprayer unit is finished a test of the fully integrated MVP1 needs to be performed. Also, the CAROB robot for the LSP in Greece is at the time of writing of this document still under construction. However, the communication hardware & software of this model will be exactly the same as of the tested CEOL.

As described in deliverable 5.1 in section 2.2.6 and 2.2.10 it needs to be verified in the field that the CAROB robot aborts a mission and stops in case the implement issues a critical failure condition on the CAN/ISOBUS. As this should be done by placing appropriate test objects in front of the analytics camera(s) a more advanced stage of the analytics module is required. This is still work in progress but to be expected to be possible when reaching in month 15 (March 2022) of the project milestone MS14: Tests for MVP1 completed.

4 LSP 3 – Spain

4.1 Description

The LSP3 is apple orchard spraying with a tractor in Spain. The sprayer is pulled by the tractor. For the MVP1 as tractor the newly purchased R4C tractor will be used.

The following components are needed to perform the LSP. The responsible project partner for providing the component is listed in brackets.

- Smart Implement: tractor-pulled EOLO 2000 sprayer (TEY) equipped with camera-based analytics module (AUA) that is able to detect diseases and adjusts spray volume (via ISOBUS).
- Vehicle: as vehicle a newly purchased New Holland tractor will be used. For the MVP1 it will not be used in autonomous mode in 2022 but manually driven.
- Farming controller: Network based FC as developed in the R4C project (LMS)

4.2 Proven integration

During an integration at AGC in Toulouse in November 2021 the modules already available for this LSP were integrated. Mechanical and electrical connections were tested. Data communication between the different modules were tested.

Figure 16 shows a visual of the tractor-pulled EOLO 2000 sprayer (TEY) to be used in LSP3. This sprayer uses the same cable harness and Electronic Control Unit (ECU) and the same crop perception hardware as described above in the LSP2 (see section 3.2). As such all electrical connections and communication protocols have been integrated and tested.

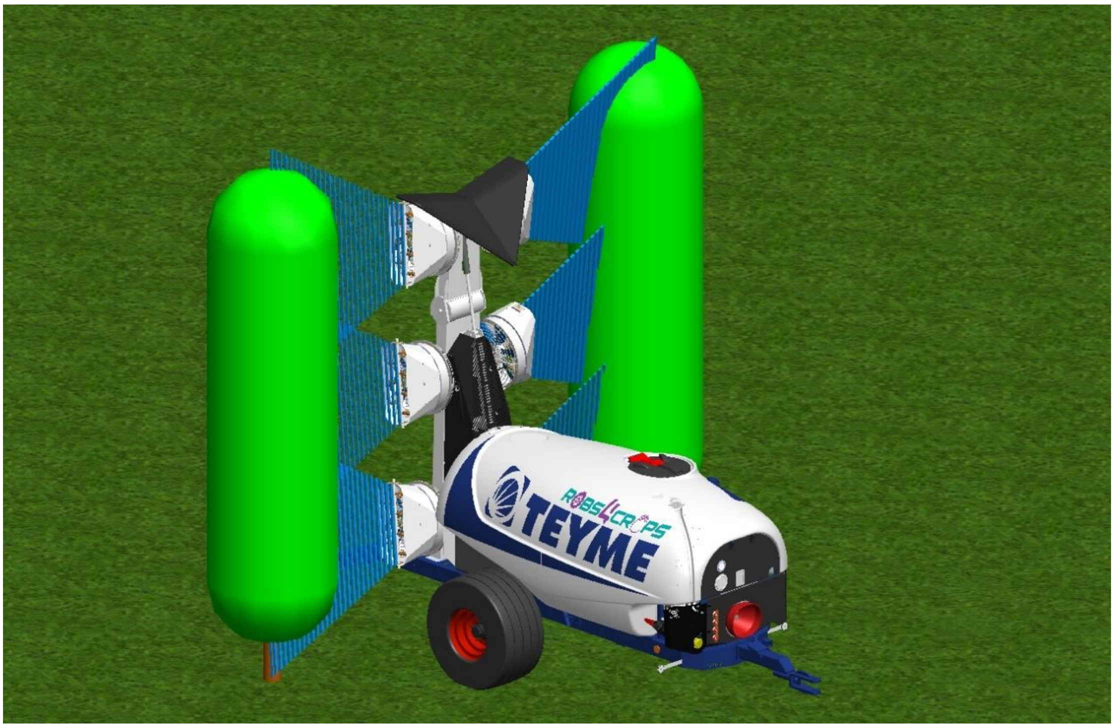

Figure 16: Tractor-pulled EOLO 2000 sprayer (TEY)

A newly purchased New Holland T4-100F, narrow width orchard tractor will be used (Figure 17). Before the pilot starts, the tractor will be equipped with an AGC-box controller (AGC) that makes information on the vehicle speed and vehicle position available on the ISOBUS

(EUT). For MVP2 and MVP3 the tractor will be fully retrofitted for autonomous navigation, but as this is still work in progress, in 2022 the tractor will be manually driven only.

Figure 17: New Holland T4-100F, narrow width orchard tractor (to be retrofitted for MVP2 and MVP3)

For the MVP1 communication between implement (sprayer & crop perception) and the vehicle (manually driven tractor) and the FC can be done in the two ways described above in the LSP2 (section 3.2). This equivalent communication structure is possible because the tractor will be equipped with the same controller (AGC-box) that is used in the CEOL and CAROB robot. In this way data logging will be possible using the FC.

4.3 Additional tasks

As the tractor purchase and delivery is still in progress the tractor is not yet equipped with the controller (AGC-box) and an ISOBUS socket. It was agreed on a time planning such that this integration is completed and tested before the tractor is needed at the LSP3 site.

As described in deliverable 5.1 in section 2.3.6 and 2.3.10 it needs to be verified in the field that the implement (crop perception module and ECU of the sprayer) generates the correct disease detection and sprayer malfunction information. As this should be done by placing appropriate test objects in front of the analytics camera(s) a more advanced stage of the analytics module is required. This is still work in progress but to be expected to be possible when reaching in month 15 (March 2022) of the project milestone MS14: Tests for MVP1 completed.

5 LSP 4 – The Netherlands

5.1 Description

The operation in LSP4 in 2022 is mechanical weeding with the Robotti in pumpkins. The pumpkins will be seeded in a square pattern and the weeding will be performed in the seeding direction as well as perpendicular to the seeding direction.

The following components are needed to perform the LSP. The responsible project partner for providing the component is listed in brackets.

- Autonomous vehicle: Robotti (AGI/SAT)
- Smart Implement: mechanical weeder (including camera based row steered sideshift module) (ABE/SAT). The implement is equipped with one or more cameras (originating from the Robotti) + analytics software to detect the weeding quality and anomalous conditions using analytics hardware and software (WR).

- Fuse box/electrical cabinet to be mounted on the weeder (ABE).
- Hardware and software for middleware PC (UHOH/WR)
- Farming controller: FC as developed in the R4C project (LMS)

5.2 Proven integration

During an integration meeting at AGI in Aarhus in November 2021 the modules needed for this LSP were integrated. Mechanical and electrical connections were tested and found to be working. Data communication between the different modules were tested and found working.

Figure 18 shows the mechanical weeder implement used in LSP4. To make the implement smart, several cameras will be attached to the implement in such a way that the analytics software is able to detect anomalous conditions that might occur during the weeding operation. As cameras the existing cameras of the Robotti will be used but they will be relocated from the Robotti and mounted on the implement. It was proven that live images can be acquired by the analytics module over the network using ROSbridge[3]. This is illustrated in Figure 19.

Figure 18: Mechanical weeder implement used in LSP4 (left photo) and weeder implement together with the side shift module (right photo)

[3] ROSbridge: http://wiki.ros.org/rosbridge_suite

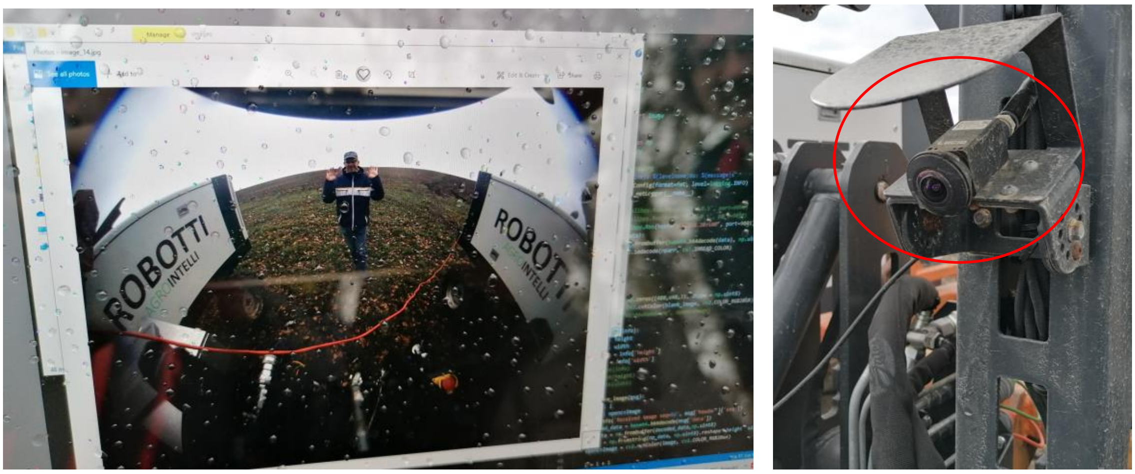

Figure 19: Live image stream of Robotti cameras received by the analytics module (left picture) and camera hardware (right picture)

It was verified that the electronic box containing the middleware and weeding analytics industrial PC (Figure 20) can be mounted on the implement. Successful tests were conducted in connecting the ISOBUS cable from the box to the Robotti (Figure 21 and Figure 22).

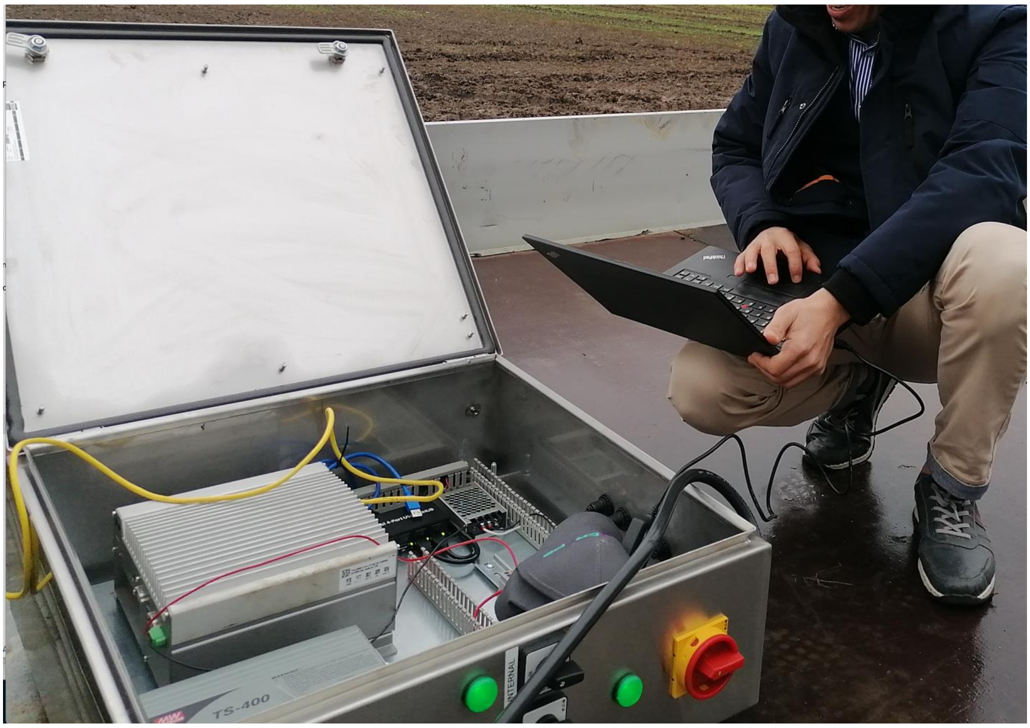

Figure 20: Middleware PC placed inside electrical cabinet, connected and powered by Robotti via the thick, black cable in the foreground.

Figure 21: Electrical cabinet/Fuse box (encircled) connected to Robotti

Figure 22: Confirmed ISObus/power connection of middleware to robot

Figure 23 shows the model of Robotti that will be used as autonomous vehicle in the LSP4. To define a new mission and for autonomous navigation the existing planning module of AGI will be used. This was tested and proven to work (Figure 24).

Figure 23: Robotti as autonomous vehicle

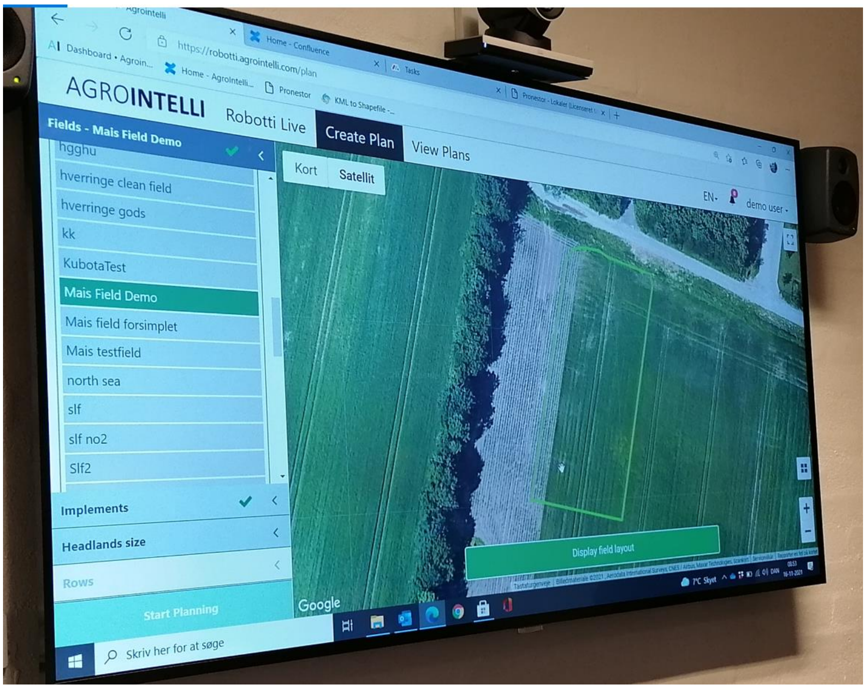

Figure 24: Mission planning module of AGI

Because the same hardware and software for analytics and middleware is used in LSP4 as in LSP1 it was proven in the same way that the weeder analytics module can communicate using ISOBUS/CAN messages with the middleware. For reference see Figure 4 and Figure 5 above. In addition in Figure 25 it is shown that middleware can communicate by means of CANopen messages with the Robotti, in the future this will be changed to full-fledged ISOBUS protocol. It was proven that the Robotti can receive commands from the implement (middleware) to abort an operation (Figure 25, right photo).

Figure 25: ISObus terminal showing live status information of the Robotti and of the analytics module (left photo: status information, right photo: emergency stop message)

Bidirectional communication between the FC and the Robotti have been proven by connecting to the the Wi-Fi access point of the Robotti and exchanging messages using the ROSbridge protocol. Figure 26 shows for example a screenshot of the FC receiving live position information from the Robotti. Figure 27 shows the proof that it is possible to send a command (start/stop/abort mission) from the FC to the Robotti. As for LSP1 the communication between the FC and the analytics software was proven to work through the middleware using websockets (Analytics => (CANbus) => Middleware => (websockets) => FC.

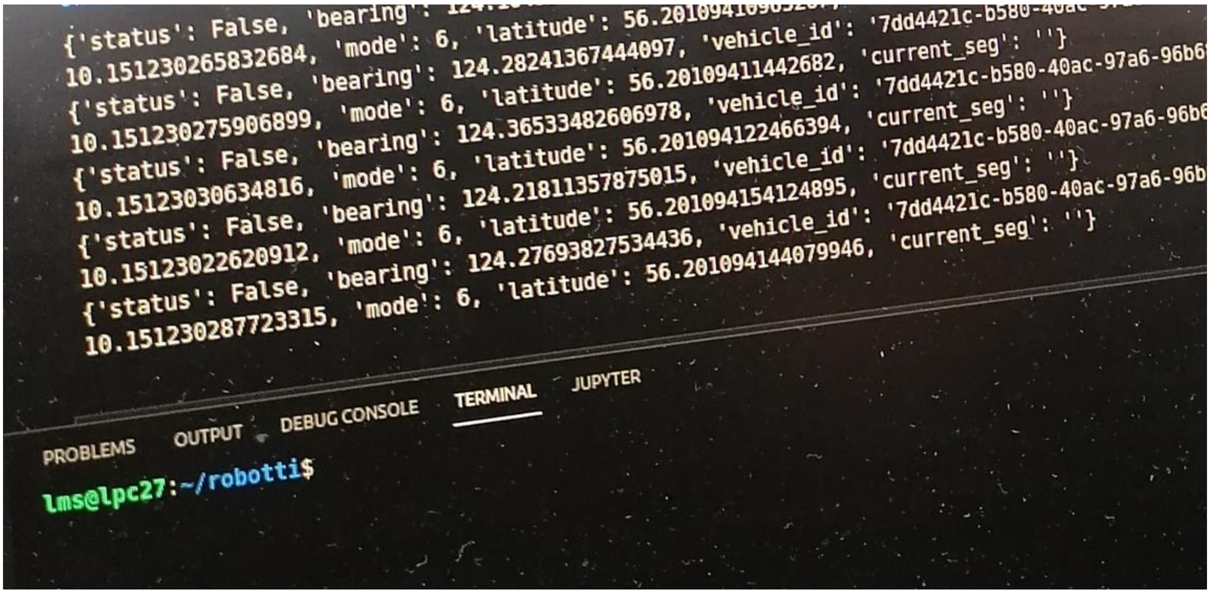

Figure 26: Screenshot of farming controller receiving live position information from Robotti

Figure 27: Starting and stopping real Robotti by commands from the FC

5.3 Additional tasks

It is work in progress to fully implement the CAN/ISOBUS communication between the weeder implement (middleware) and the Robotti.

As described in deliverable 5.1 in section 2.5.6 and 2.5.10 it still needs to be verified in the field that the Robotti aborts a mission and stops in case the implement (analytics module) issues a critical failure condition on the CAN/ISOBUS. As this should be done by placing appropriate test objects in front of the analytics camera(s) a more advanced stage of the analytics module is required. This is still work in progress but to be expected to be possible when reaching in month 15 (March 2022) of the project milestone MS14: Tests for MVP1 completed.

6 Farming Controller and Digital World Model

Concerning the functionality of the FC to be realized as MVP1 in Table 1 (page 5) it is defined: "Digital World Model is updated with information from vehicle and implement". This topic has so far not been addressed by the individual LSP chapters above. However, the FC will work in the same way for all LSPs the current state is described in this chapter.

As depicted in the previous chapters it has been proven for all LSPs that the FC can receive information like GNSS-based position and weeding/crop quality from the robots. It was demonstrated that in the FC a virtual robot can move in a digital world based on pre-defined path data. The virtual robot does react on (virtual) sensor data, such as replanning its path to avoid an obstacle. Figure 28 shows a screenshot of such a digital world.

Still work in progress is to write software that uses the received information from the real robots to update the Digital World Model, such as building a digital elevation model from the altitude component of GNSS position data.

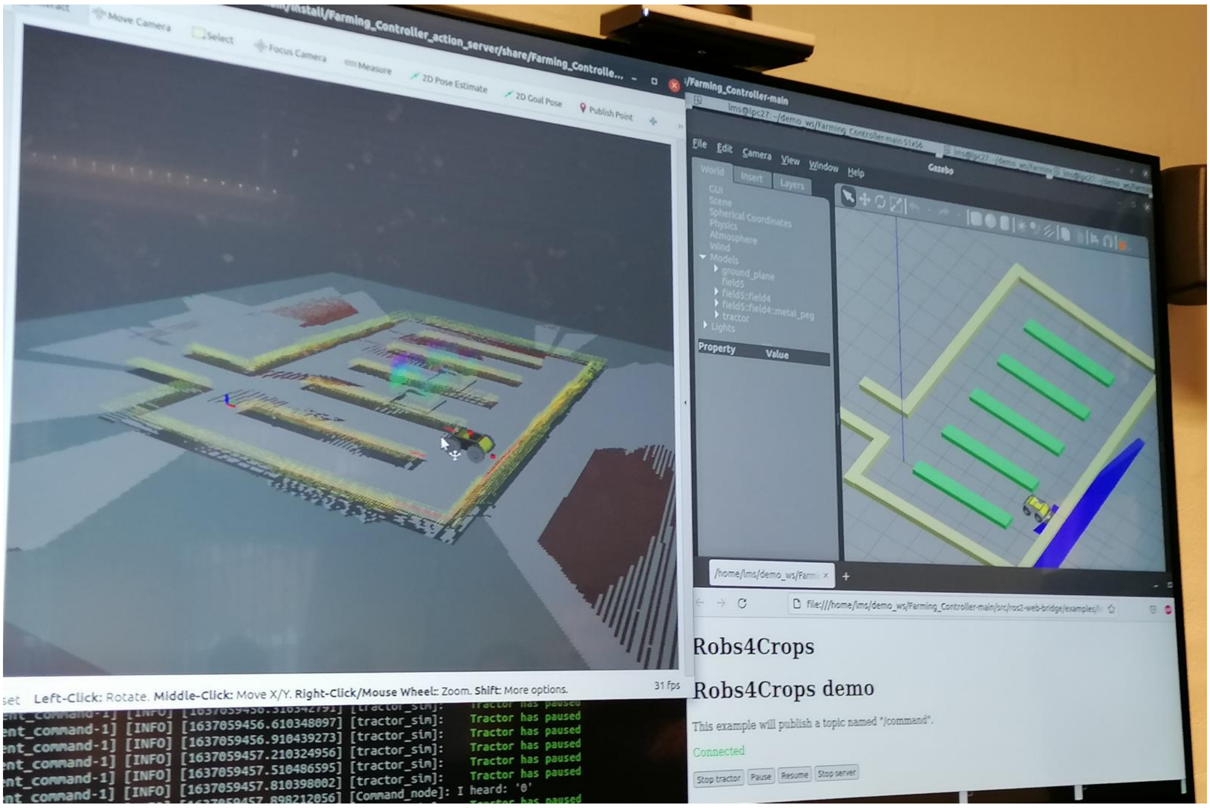

Figure 28: FC demonstrates digital world model

7 Conclusions

This demonstrator deliverable illustrates the current state of the integration of the working combinations of coordination software, vehicles and implements to be used as MVP1s in the four different large scale pilots of the project. For all pilots, mechanical and electrical connections were tested and found to be working. Data communication between the different modules were tested and found working. For some LSPs, some hardware modules are still under construction, such as the sprayers to be used in the pilots in Greece and Spain. However, by having available already the completely functional electric harness of the sprayer , validating the full system functionally was successful. For the LSP3 in Spain the MVP1 will not use a tractor with autonomous navigation but a tractor with a human driver. Full retrofitting of the newly purchased tractor will happen during 2022 season. The communication capabilities of the computer vision based analytic modules for the smart weeders and the smart sprayers were successfully tested with respect to their communication capabilities. It still needs to be verified in the field that the robots stop and abort a mission in case these modules issues a critical failure condition. To test this mission abortion, a more advanced version of the analytics module is required. The analytics module is still work in progress but is expected to be complete in month 15 (March 2022) in time for project milestone MS14: Tests for MVP1 completed.