D2.4 Methodologies to assess the real-time performance of the implements (1)

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Abstract:	The script will describe the algorithms that are going to be developed and employed for assessing the real-time dynamic performance of the smart implements in terms of the operations performed by including the optimization criteria and user requirements.

Document Revision History			
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FC	Farming Controller
VT	Virtual Terminal
ECU	Electronics Control Unit
IBBC	ISOBUS breakaway connector
CAN	Controlled Area Network
WUI	Web User Interface
GUI	Graphical User Interface
PTO	Power Take-Off
PWM	Pulse Width Modulation

1 Introduction: In-field performances of Smart Implements

The main aim of the script is to focus on enlightening the methodologies to evaluate the in-field performance of the developed smart implements with the work package 2. This will be provided by the following sections 2-7.

Sections 2, 3, and 4 are describing the evaluation of the dynamic in-field performance of the vehicle and smart sprayer in two combinations: (1) sprayer-retrofitted tractor; (2) sprayer-CEOL robot. For evaluating the dynamic performance of the sprayer for both scenarios, the parameter to process will be the "as-applied" rate resulting from the in-field task application of spraying.

In sections 5, 6, and 7, the evaluation method of the dynamic in-field performance for the smart weeder that is attached to autonomous agricultural robots (CEOL and Robotti) will be carried out. For the dynamic performance of the weeder, the parameter to process will be the quality assessment of the weeding operation that is resulted from differentiating the front and rear camera/sensor detection.

2 Pilot cases with the smart sprayer (Greece and Spain)

A commercially available sprayer for agricultural applications that is developed by TEYME, especially for grape and apple orchard applications, will be equipped with all the necessary technology and sensors to transform it into a "smart implement". The sprayer will be designed with the sensor system of PWM nozzles for a variable rate of spot-specific phytosanitary application. Besides that, a set of electrohydraulic distributed fan systems that is specific for variable rate application of airflow will be implemented. The developed smart implement will employ the variable rate during the application. The application rate will be combined with the information, such as canopy volume and disease detection, from the perception system. The perception system is developed by AUA. The smart implement will be defined by the implementation of the architecture design into the sprayer (Fig. 1).

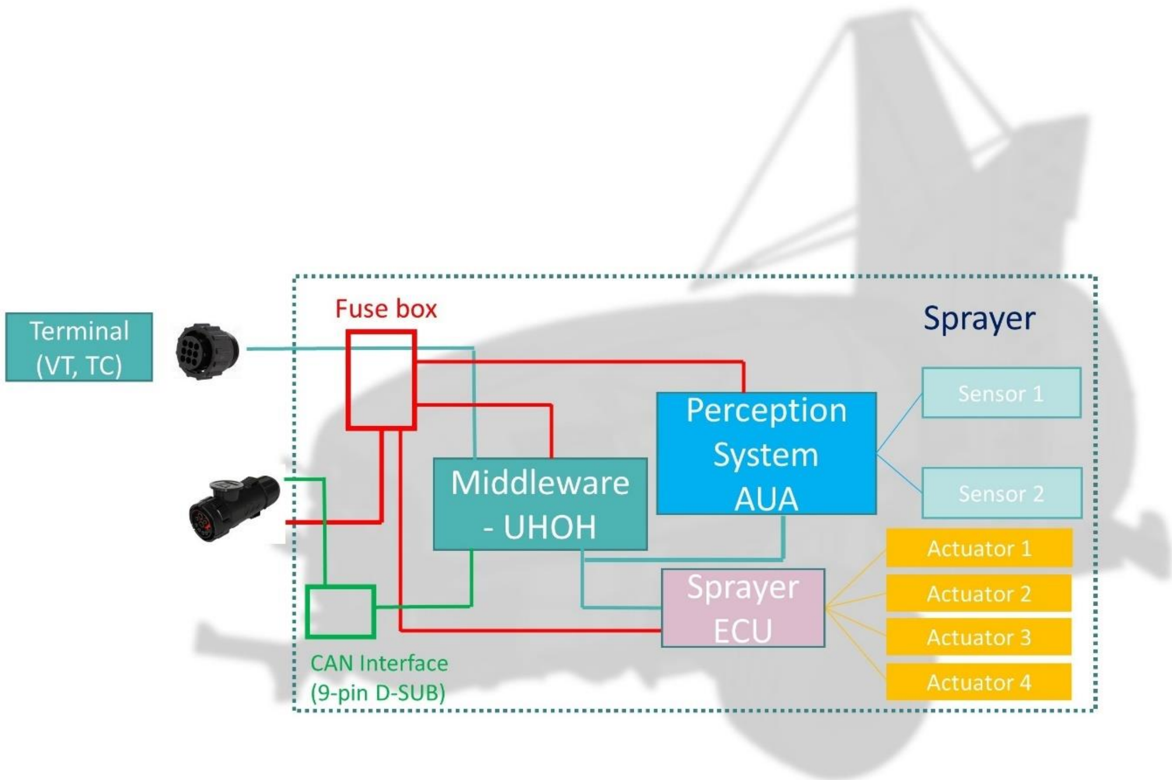

Figure 1. Schematic view of the smart sprayer.

Two current commercial sprayers are upgraded: The ASM 200 for the vineyard pilot (Greece) and the EOLO 2000 for the orchard pilot (Spain) are being upgraded to be capable to carry out precise spot-specific targets phytosanitary applications and provide ISOBUS compliant communication with vehicles.

Following activities are being carried out to implement the following functionalities:

Mechanical design

- Upgrade from PTO single fan to 8 independent fans with hydraulic proportional control for EOLO 2000.
- Upgrade from PTO single fan to single fan with hydraulic proportional control for ASM 200.
- Upgrade from PTO-driven PUMP to hydraulic-driven PUMP with proportional control for ASM 200.
- Upgrade from 2 sections ON-OFF spraying Left-Right to 8 independent vertical sections with PWM nozzles for variable rate application.
- Upgrade from manual valves for cleaning and mixing tank functionalities to electronic valves for automatic operations control.
- Mechanical design to integrate the foreseen real-time perception System unit and the middleware computer.

Electronics design

- ECU Sprayer configuration programming to assure ISOBUS compliant communication within the vehicle, perception system, and middleware.
- ECU Sprayer low-level commands for actuators programming for real-time execution of spot-specific spraying, cleaning, and mixing tank operations.

Methodologies to assess the real-time performance of the implements

- ECU Sprayer programming for data collection of sensors (flowmeters, pressure sensors, and nozzle performance measuring sensors), task results, and alarms to be sent back to the FMIS. A combination of all the sensors is supposed to give accurate as-applied information.

Harness design and manufacturing for sprayer electronics architecture.

The developed sprayer will be connected to the vehicle, in terms of the retrofitted tractor and robot (CEOL), for different pilot cases that will be described in the sub-sections below.

3 Retrofitted tractor and Smart Sprayer

The sprayer that is developed by TEYME will be designed with ISOBUS, in terms of an ISOBUS compliant ECU functioning with a task controller for the field application. Besides that, to be able to connect to the developed middleware, the implement bus (ISO 11783-compliant) will be designed with a D-SUB9 connector which the pin-assignment should be organized to make it as "transceiver". The transceiver will enable communication between the middleware and the implement bus. Since the bus of the implement is ISO 11783 compliant, it should also include the ISOBUS breakaway connector (IBBC) to be able to communicate with the retrofitted tractor.

The field application task, in terms of the prescribed rate and geo-location of the boom, will be uploaded through the dedicated virtual terminal (VT) of the TEYME sprayer. The response of the sprayer so-called "as-applied" rate to the prescribed rate will be recorded by the dedicated VT of the sprayer. Simultaneously, the recording would be done by the developed middleware. The middleware also will be responsible for sending the as-applied rate to the farming controller (FC). Eventually, the as-applied rate as it is the in-field performance of the sprayer could be represented on the FC or FMIS web interface in real-time with a specific frequency. In the first draft solution, the as-applied rate also could be represented on the middleware interface in real-time. The data flow can be seen in the architecture below in Fig.2.

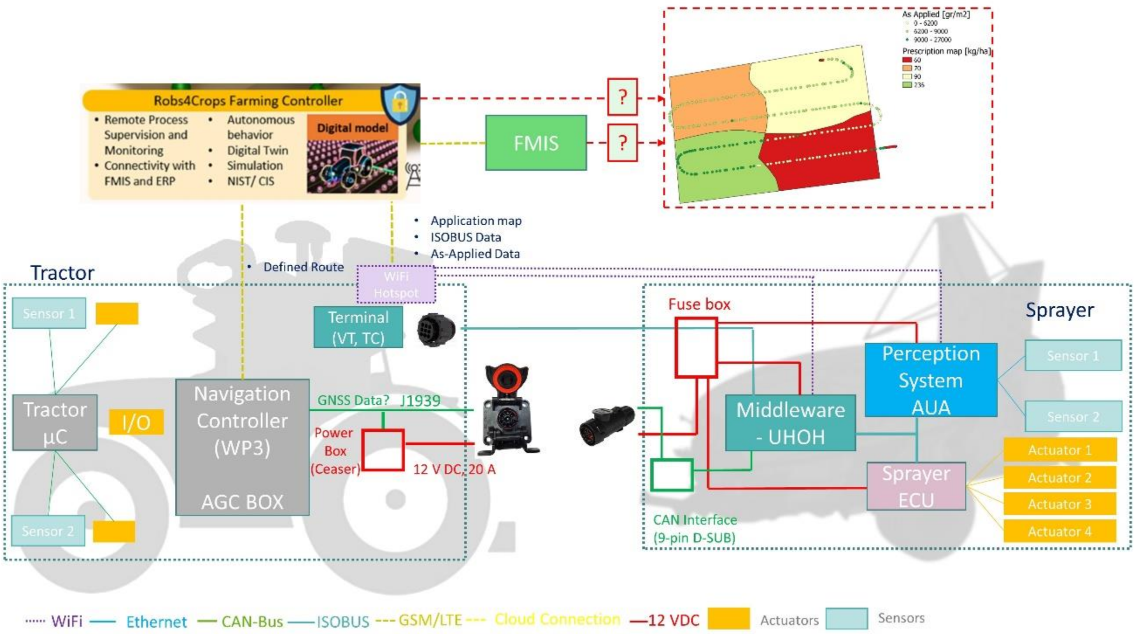

Figure 2. The in-field performance of the sprayer in combination with the retrofitted tractor.

4 CEOL robot and Smart Sprayer

With the combination of the CEOL robot and the sprayer, the above-mentioned sprayer will be employed. It requires the J1939 CAN protocol to be implemented into the CAN bus system of the robot to enable communication between the robot and sprayer. Then the VT will be connected to the bus using a 9-pin in-cab ISOBUS connector. The VT will be responsible for executing the application task or controlling the job, in terms of sending the prescribed rate and receiving the as-applied rate to/from the sprayer. The communication will be established using the ISOBUS Breakaway Connector (IBBC) between the robot and the sprayer. The middleware will be responsible for the same task as described above in section 3. In the architecture represented in Fig.3, a temporary (draft) solution, where the VT establishes the communication through the middleware, is described. This is only until the J1939 protocol is implemented into the CANBUS of the CEOL robot.

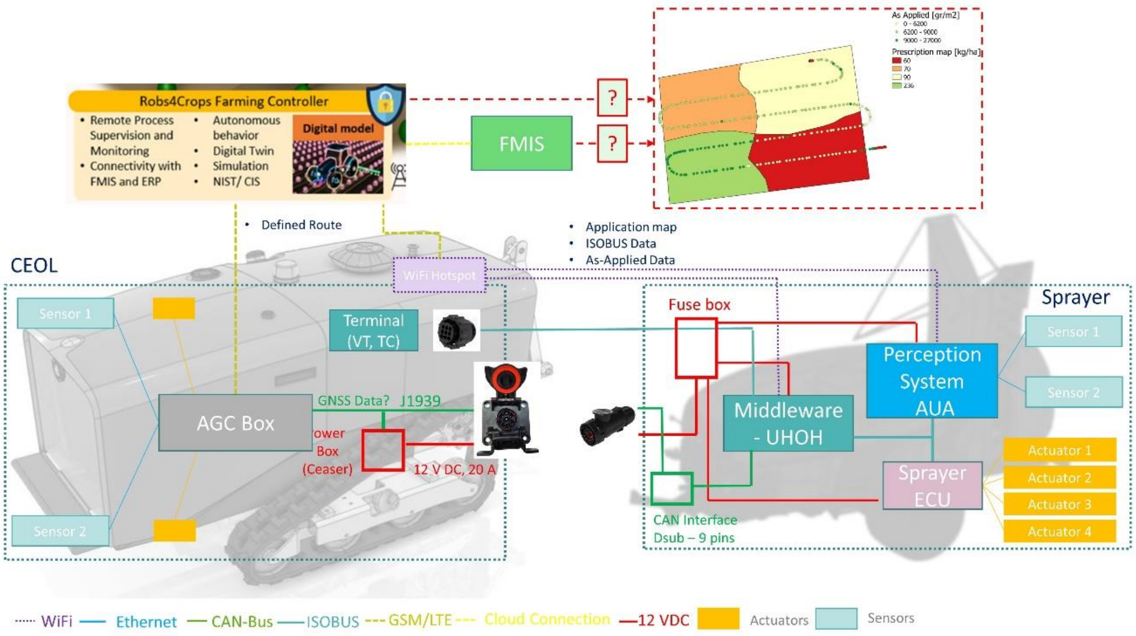

Figure 3. The in-field performance of the sprayer in combination with the CEOL robot.

The parameters to evaluate the in-field performance of the sprayer as these are defined by the partners involved are given and explained in Table 1.

Table 1. Parameters to evaluate the in-field performance of the sprayer

Partner	Description of the Task	Parameter for the in-field performance
UHOH	Communication based on the ISOBUS with all the necessary components, representing the necessary information, recording the	As-applied rate

	as-applied rate and sending it to the VT as well as to the Farming Controller	
TEYME	Communication based on the ISOBUS with the middleware and the perception system. Execution of tasks according to middleware consigns. Data collection from flowmeters for independent section phytosanitary rate feedback, from inductive sensors of hydraulics fan speed control, from hydraulic pressure sensors for energy consumption calculation, and pressure sensors on the hydric phytosanitary system.	As-applied phytosanitary rate
AUA	Communication with the middleware as well as with the sprayer ECU through the CANBUS based on the ISO 11783 protocol. Defining/correcting the prescribed rate based on the sensor information would be the main function.	Prescribed rate from the TC (Task Controller of VT)
AGC	CEOL will be responsible for communicating with the Implement and providing the necessary data such as position and speed information. It will also be able to receive commands such as emergency/side shift. Furthermore, CEOL communicates with the FC for navigation purposes as well as emergency cases.	Emergency stop GNSS position and speed information feed
LMS	Communication based on WebSocket through a JSON formatted string will be sent. This file will contain either the ISOBUS data, recording the as-applied rate, or the robot data recording robot status data, and sending it to the Farming Controller	As-applied rate information from the implement

5 Pilot cases with the smart weeder (France and Netherlands)

On large-scale pilots, smart weeders will be deployed in the Netherlands and France. In the Netherlands, a weeder will be used in row crops in a potato crop rotation. The weeder will be mounted with a three-point hitch to the Robotti robot from AgroIntelli. On the weeder, a standalone machine vision-based side-shift will ensure the most accurate guidance along the crop rows. On the French large-scale pilot, the weeder will be mounted behind the CEOL robot and will weed between the vine stocks. During the weeding operation, the weeder will be monitored with industrial 2D color RGB cameras that record the crop before and after weeding. The before and after weeding operation images will be compared with the desired situation to enable monitoring signals such as weeding quality and emergency stop situations because of crop damage.

6 CEOL Robot and Smart Weeder

Since the weeder is not ISOBUS compliant, it will be designed with the analytics software that will play the role of the bus communicating with the attached sensors and the developed middleware. Besides that, the analytics uses the camera from the Robotti/CEOL for monitoring and vision analysis. The middleware will transmit the received messages from the analytics to the ISOBUS compliant terminal (VT). For the VT, the ISOBUS mask will be designed and later will be implemented into the VT. The mask will present/include all the needed parameters that evaluate the in-field performance of the weeder (Fig. 4).

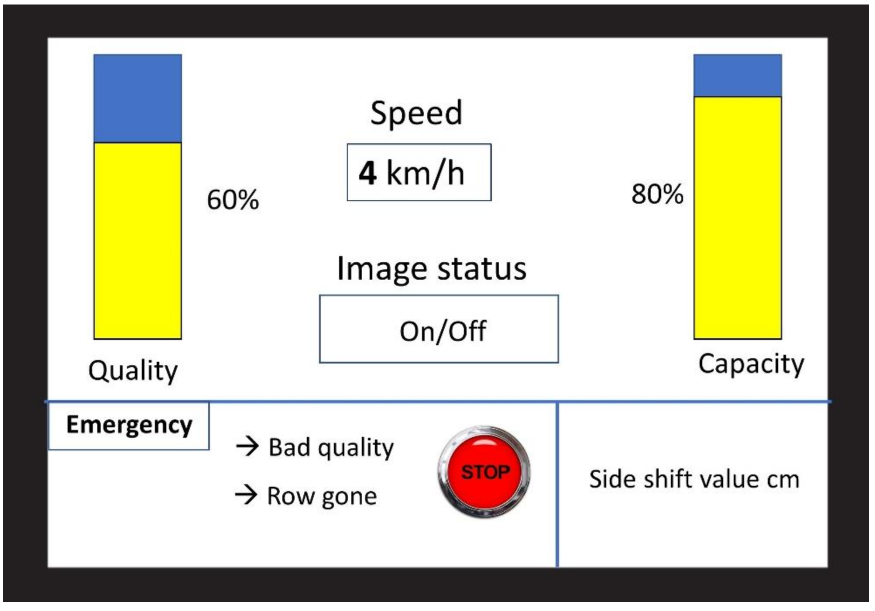

Figure 4. The ISOBUS mask for the weeder performance.

The parameters that will be requested from the CAN bus are:

- Actual speed (Ground-based Speed)
- Working width (Coverage from the path)

Subsequently, the capacity is in hectares/hour and could be defined by a combination of the working width and actual speed. The work quality is defined as how well have weeds been removed, how close to the crop the weeder has been working. Furthermore, the accumulation of weeds and soil in the implement, accumulation that can decrease rapidly the quality of the mechanical weeding, and eventually cause an emergency stop will be measured by the cameras.

Besides that, the ratio between crop growth and weed density is important. Crop growth stage and crop size is normally a parameter to set up during weeding with camera systems. There is also a need of defining the crop damage threshold for autonomous weeding. It will be assumed that no damage is accepted from a robot, whereas a driver could lead to 5% crop damage. For evaluating the weeder performance, visible markers will be organized/placed aboveground, of where the knives are operating underground, otherwise, it is impossible to measure how the weeder is performing. The active sections of the weeder should be visualized and tracked (AGC). In grapevine it happens that only the left or right side of the machine is active, and not the complete working width, this affects capacity as well.

In the first step of the development, the ISOBUS mask will be implemented in the middleware as it is the temporary solution for the development phase (shown in Fig. 5). It will be shifted to the VT later in the next step as a permanent solution. It will be examined if the ISOBUS mask can be integrated into the web user interface (WUI) of AGC as a permanent solution since the mask integrated with the WUI communicates (transmits and receives) with the CAN bus of the robot. The described communication between the CEOL and the weeder for the pilot case in France is presented in Fig.5.

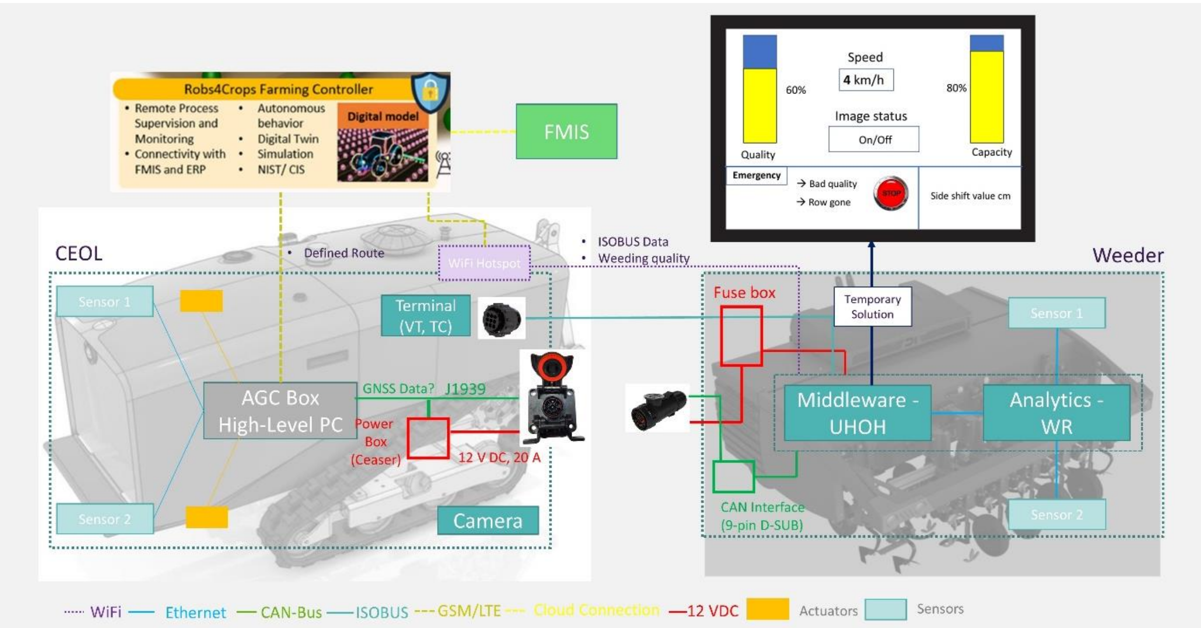

Figure 5. The in-field performance of the Weeder in combination with the CEOL robot.

7 Robotti and Smart Weeder

For the pilot case in the Netherlands, the weeder will be connected with the Robotti (AGI). The same procedure will be applied for the communication between the Robotti and the weeder. In the first step of the development, the ISOBUS mask will be implemented in the middleware as it is the temporary solution for the development phase (shown in Fig. 6). It will be shifted to the VT later in the next step as a permanent solution. AS with AGC above, it will be examined if the ISOBUS mask can be integrated into the web user interface (WUI) of AGI as a permanent solution since the mask integrated with the WUI communicates (transmits and receives) with the CAN bus of the robot. The described communication between the Robotti and the weeder for the pilot case in France is presented in Fig.6. The assessment of the in-field performance of the weeder will be carried out as it is described in section 6.

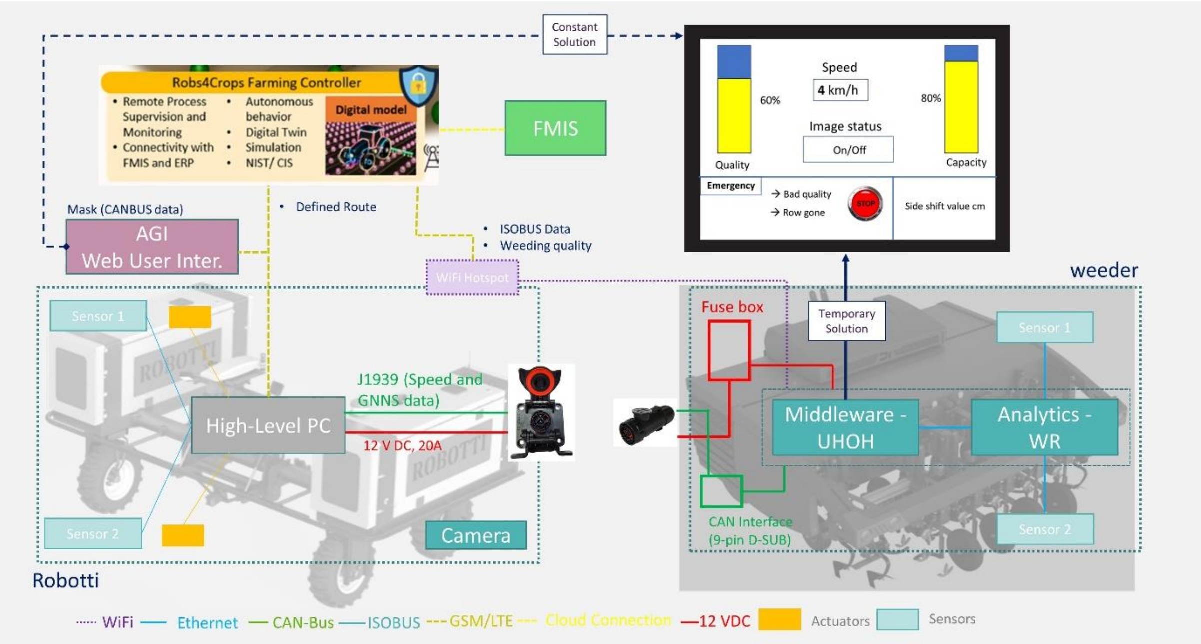

Figure 6. The in-field performance of the Weeder in combination with the AGI Robotti.

The parameters to evaluate the in-field performance of the weeder as these are defined by the partners involved can be seen in Table 2.

Table 2. Parameters to evaluate the in-field performance of the weeder

Partner	Description of Task	Parameter for in-field performance
UHOH	Communication based on the ISOBUS with all the necessary components, especially with the Analytics of the weeder, representing the necessary information, recording the quality of the work, and sending it to the VT / ISOBUS mask as well as to the FC	Quality of the weeding process, crop damage vs weed destruction, emergency stops due to blockage
WR	Developed analytics system communicates with the implement (weeder) /middleware through a virtual channel since the	Quality of the weeding process, crop damage vs weed destruction, emergency stops due to blockage

	middleware and the analytics run on the same computer. The analytics receives sensor/camera data from the Robotti/CEOL from a separate channel to process the weeding quality and machine capacity. The processed information will be shared with the middleware	
AGC	The CEOL will be responsible for communicating with the implement and providing with necessary data such as GNSS position and speed information. It will also be able to receive commands such as emergency/side shift. Besides, CEOL communicates with FC for navigation purposes as well as emergency cases.	Emergency stop GNSS position and speed information feed
AGI	CANBUS communication uses the J1939 protocol to send the signals: machine speed, machine distance, and machine direction. Using the cameras on Robotti, ensuring the communication and images are sent to the middleware. A GUI will be created that is able to present the information processed from the middleware.	Quality of the weeding process
LMS	Communication based on WebSocket through which a JSON formatted string will be sent. This file will contain either the ISOBUS data, recording the weeding quality, or the robot data recording robot status data, and sending it to the Farming Controller	Weeding quality from the implement