Connecting agricultural robots and smart implements by using ISO 11783 communication

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Abstract: Agriculture is facing many challenges that are related to increased prices of farming inputs, labor shortage, and climate change. Advanced machines and autonomous vehicles as well as sensor systems with increased capabilities are now present on the farm and can offer solutions to these challenges but the issue that remains is how to connect the components involved in forming an integrated digital farming system. At the same time, ISO 11783 (commonly designated as ISOBUS) is playing a substantial role in farming and an increasing number of ISOBUS-compliant machines can be seen among the farm machinery. Under this perspective, the newly funded H2020 project Robs4Crops is trying to combine agricultural robotics with the already existing implements by leveraging ISOBUS. The aim is to integrate autonomous vehicles into the available farm infrastructure and not include them as proprietary solutions. In addition, the project aims at increasing the intelligence of the implements by using sensors and analytics that in real-time can assess the efficiency of the operation performed and subsequently, by using ISOBUS, inform the robots in order for the latter to take relevant action. This work describes the development of perception units for spraying and mechanical weeding machines and how these “intelligent” implements are using ISOBUS to communicate with two different agricultural robots. From the existing results, it is becoming clear that ISOBUS can play an important role in introducing agricultural robots in farming but also facilitate the cyber-physical connection between the implements and the cloud-based solutions (e.g. digital twins).

Keywords: Autonomous vehicles, digital twins, farming controller, ISOBUS, smart farming.

1. INTRODUCTION

The most important challenge in European agriculture is the cost and scarcity of labor. The cost of labor affects the profitability of farming while the scarcity of labor threatens its very existence. This is illustrated vividly by the current COVID-19 pandemic, with many EU countries not being able to accommodate seasonal agriculture tasks, due to restrictions in welcoming field workers from abroad. As a result, some crops cannot be harvested and must be left on the field, resulting in increased food waste, food insecurity, and extensive financial losses.

Robots have replaced labor in several sectors of the economy. The industrial robotics market is projected to reach $75.3 billion by 2026 while in the same year the agricultural robotics market is estimated to be worth $11.9 (The Markets Reports, 2022). Although agricultural robots can offer solutions to mitigating labor shortages (Marinoudi et al., 2019), they need to overcome specific barriers to reach a wider acceptance. From a technical point of view, they do not reach their full potential because they are used as unincorporated units rather than part of a complete, robotic system with proper communication with agricultural implements (Fountas et al., 2020).
Combining diverse expertise (i.e. industrial, agronomic, social) and engaging relevant stakeholders with great market impact, the newly funded H2020 project Robs4Crops aims at addressing both technical and non-technical challenges related to agricultural robotics. Regarding technical challenges, farming implements need to obtain upgraded capabilities (smart machines), while tractors and vehicles need to be fully autonomous when handling obstacles and other unexpected situations. Moreover, planning and scheduling of complete field tasks must consider agricultural constraints, while the proposed solutions need to be flexible and modular, to be applicable in several field scenarios and conditions.

Based on these principles, a core aspect of the Robs4Crops project is to use standards that are already utilized in agriculture. One of them is ISO 11783 (commonly designated as ISOBUS) with more than 25 years of offering an interface for connecting tractors with implements (Oksanen & Auernhammer, 2021). At the same time, many research efforts are focusing on ISOBUS, targeting expanding it (Paraforos et al., 2019), and using it for developing methodologies to increase the efficiency of the agricultural operations performed (Heiß et al., 2022; Sharipov et al., 2021). Despite the fact that the ISO 111783 standard is extensively implemented in today’s technologies of precision agriculture (Gerhards et al., 2022), there are very limited research studies on its application with the horticulture implements together with the robots and tractors that are J1939 standard compliant.

This paper aims to present a conceptual framework on how the ISOBUS could be integrated into autonomous agricultural vehicles connected to smart implements, with enhanced capabilities in terms of context-awareness and real-time performance assessment, but also to advanced cloud-based solutions such as the farming digital twins. The novelty of the present work can be seen in the approach to using an industry-standard such as the ISOBUS in connecting machines with advanced cognition capabilities forming a holistic and interoperable robotic system.

2. MATERIALS AND METHODS

2.1 Robs4Crops project

In the frame of the Robs4Crops project, an agricultural robotic system was developed, which will in the first instance be used for spraying and mechanical weeding but it has much wider applicability. The robotic system aims to minimize commercial and technical risk by using elements from current agricultural practice: the project incorporates existing agricultural robots, existing farm tractors, existing farm implements, existing agricultural standards (i.e. ISOBUS and three-point linkage), and it fully supports the practice of combining tractors and implements in a variety of configurations. However, the employment of the ISOBUS functionalities such as TECU and TIM will be challenging since the ISOBUS compliant implements (sprayers and weeders) are expected to communicate with robots and tractors that don’t comply with the J1939 standard at the current phase of the project.

2.2 Commercial machines and robotic platforms

The ASM sprayer (TEYME, Lleida, Spain), which can be seen in Figure 1 was chosen to be attached to the CEOL robot (Figure 2) (AgreenCulture, Toulouse, France) for chemical application in table grapes in vineyards in Greece and Spain. The CEOL is also used in combination with a mechanical weeding machine in vineyards. The Robotti (Agrointelli, Aarhus, Denmark), which can be seen in Figure 3, is being used together with a mechanical weeder for vegetable production in The Netherlands.

Figure 1. The ASM sprayer from TEYME.

Figure 2. The CEOL from AgreenCulture with a mechanical weeding machine.
2.3 Smart sprayer case

The smart sprayers support the entire application loop ranging from perception up to decision and actuation. The sprayer system was equipped with a perception unit capable of estimating the canopy profile on an ad-hoc operation and applying only the necessary spraying amount based on the crop canopy size and structure. The smart prototypes utilize high-end actuation components like a proportional fan and proportional solenoid electro-valves combined with drift reduction nozzles, to minimize the off-target application of pesticides.

2.4 Smart weeder case

The weeding implement is equipped with RGB cameras to assess the status of the crop after the implement has passed; in this way, insufficient weeding or the occurrence of crop damage is detected and an appropriate error message is sent through ISOBUS to the supervision software and the robotic platform. The middleware software on the smart weeder generates and stores the as-applied information in terms of weed pressure and operation performance.

2.5 Farming controller

In the initial phase, the farming controller offers a digital representation of the farm prior to the autonomous robotic agricultural processing and updates this model in real-time based on the information coming from the autonomous vehicle and implement sensors on a frequent basis. The objective is to design and implement a high-level control and optimization system, to execute autonomous farming operations. The farming controller is using knowledge from industrial manufacturing (Industry 4.0), incorporating digital twin technology consumed by a service-based integration and communication platform.

2.6 Software middleware

Proper communication between the agricultural implements and the utilized autonomous vehicles is established by using software middleware. One of its main objectives is to coordinate communication between all components on the field level but also to establish communication with the cloud-based farming controller. The vehicles (CEOL and tractor) chosen for the pilot with the smart sprayer are not compliant with the J1939 protocol, in terms of not being able to follow the address claiming procedure with the ECU of the sprayer. Therefore, the middleware software was designed with a simulated TECU functionality that made the translation of the incoming messages from the vehicle (e.g. GNSS position data and speed) possible.

For the pilot with the smart weeder, the ECU of the weeder is designed or simulated in the middleware software. Therefore, the vehicles such as the CEOL and Robotti don’t have to necessarily follow the address claiming procedure in the weeder case. However, the middleware software is responsible to translate the messages coming from the vehicle as well as the analytics software of the weeder to the simulated ECU. The information coming from the vehicle is the GNSS and the ground-based vehicle speed. These for the analytics are the quality and capacity of the weeding. The middleware software is also responsible for translating the “Emergency Stop” command from the analytics software and sending it to the robot. So, it could be stated that when needed ISOBUS functionalities are missing from one component, the middleware is translating the necessary information that is sent using a proprietary communication protocol into ISO 11783 telegram format.

For the middleware, the CANoe v15 (Vector Informatik GmbH, Stuttgart, Germany) was chosen together with its ISO
11783 and J1939 options. Furthermore, the CAPL (Communication Access Programming Language) scripting, which is closely based on the syntax of the C language, offered the possibility to access all of the objects contained in the communication database (messages, signals, environment variables) as well as system variables.

3. RESULTS AND DISCUSSION

3.1 Smart sprayer prototype

In order to have complete information on both canopy sides, the developed perception unit (Figures 4) for the spraying operation was equipped with two sets of RGB-D imaging sensors facing the left and right sides of the canopy. Each sensor was mounted on a 2-DOF camera bracket, to further exploit the images’ field of view based on the vegetation geometry. This device uses the camera color stream with the purpose to monitor the crop status (i.e., nutrient deficiencies and disease detection) and the depth camera stream to estimate the canopy structure and plant architecture, in two different high-performance computing software pipelines. The perception unit was designed to be ISOBUS compliant and thus send the spraying recommendations directly to the ECU (electronic control unit) of the sprayer, which is connected to the ISOBUS.

The architecture of the smart sprayer case is presented in Figure 5. As it can be seen, the CEOL is sending position data...
and speed information to the sprayer by using ISO11783-based messages. The middleware software is responsible for recording these data, forwarding them to the components of the sprayer but also sending them to the Farming Controller. For sending the information to the Farming Controller, the middleware is designed with a virtual channel that sends the data to the Web-socket. The Web-socket is developed in Python v3 and is in charge of communication with the Farming Controller. At the same time, a developed prescription map on the Task Controller is using the position data to output the prescribed rates for the spraying operation. The perception unit is receiving this information and is updating it based on real-time sensing. The updated prescribed rates are obtained by the sprayer ECU to be applied and by the middleware software to be recorded.

The developed mask for the sprayer case that is presented to the ISOBUS terminal can be seen in Figure 6. The operator can see the treated area by the sprayer and the current position, while other information related to the process can be also seen (e.g. total time and distance covered, current rate and speed, etc.). At the moment, the sprayer can differentiate between the left and right side applying thus two different rates on two different sections as can be seen in Figure 6 (yellow rectangles). The aim is to increase the number of sections to three per side by providing the necessary information from the perception unit and by being able to control the necessary nozzles on each side.

3.2 Smart weeder prototype

The conceptual architecture of the smart weeder is presented in Figure 7. In this case, both robots are being used (i.e. CEOL and Robotti) for pulling a mechanical weeding machine and similar components architecture to the sprayer case was used. The major difference is that the implement does not have any electronic components and the ISOBUS functionalities are being totally implemented by the middleware software (Figure 8). In Figure 8 the developed ISOBUS mask can be seen in simulation mode, while the same information is presented in the actual terminal with the UT functionality in Figure 9.

The bottom line for the smart weeder is that the weeder is capable of assessing the performance of the operation to detect abnormal conditions (bad operation or even crop destruction) and take countermeasures or send error messages to the supervisor. And for that mainly cameras are used to “look” at the field (before and after/in front and behind the operation) and analyze the images/video stream from these cameras using AI (deep learning) models/algorithms. These models are trained on data collected and manually labeled first. After the training phase, the trained models are used to apply the learned rules in real-time (inference). But next to camera sensors also other data sources (speed of the vehicle, sensors for measuring rotation of weeder parts etc.) can and will be used.

Based on this process, the algorithm is assessing the quality level of the operation performed. This information is sent to the middleware software through a virtual CAN-Bus following...
electronic components and the ISOBUS functionalities are similar components architecture to the sprayer case was used. In Figure 7. In this case, both robots are being used (i.e. CEOL nozzles on each side.

perception unit and by being able to control the necessary right and left etc. see the treated area by the sprayer and the current position, the ISOBUS terminal can be seen in Figure 6. be recorded sprayer ECU to be time sensing. The updated prescribed rates are obtained by the is receiving this information and is updating it based on real time (inference). But next to camera sensors also applied and by the middleware software to the components of them to the Farming Controller.

At the same time the sp reading phase. At the moment, the sp can be also seen that sends the middleware software through a virtual CAN level of the operation performed training phase.

4. CONCLUSIONS

The overarching aim of the Robs4Crops project is to introduce robotics into common farming practice, not as a stand-alone solution but as a solution that could be integrated into the farmers’ ecosystem and also use existing machinery. For the latter to become a reality, ISOBUS can play a substantial role in connecting and interfacing commercial machines with innovative robotic solutions. The results of this work offer a conceptual framework on how this could be a reality but at the same time highlight the need for ISOBUS to include more process-related information in order to optimize the performance of the vehicle-implement combination.

ACKNOWLEDGEMENTS

The project ROBS4CROPS has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No. 101016807.

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