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Communication between agricultural robot and mechanical weeding machine based on ISO 11783 network

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Abstract: Latest technologies such as advanced agriculture implements and autonomous vehicles designed with the latest sensor technologies could partially offer a solution to the challenges in agriculture that are related to crop demands, increased cost of inputs, and labor shortage. However, the compatibility, in terms of communication between the autonomous vehicle and the agricultural implements, raises the main concern. This is because most of the autonomous robotic platforms in agriculture are not compliant with existing agricultural implements that are integrated with ISO 11783 (also known as ISOBUS) standards. Besides that, there are still few agricultural processes where the implementation of ISOBUS would fulfill farmers' needs to evaluate the performance of the implements. Weeding is one of those processes as it has a significant influence on crop growth. To address the mentioned issues, this work aims at integrating an agricultural robot with an existing mechanical weeder by leveraging ISOBUS in combination with software and hardware level.

To fulfill the aim, this paper outlines the development of a middleware that makes communication between the mobile robot and the weeder possible. In addition to that, the development of an implement object pool (IOP) for the representation of the weeder performance, in terms of weeding quality, and its integration with the simulated electronic control unit (ECU) of the weeder is discussed. A preliminary analysis and assessment defined the threshold of 10% for the weeding quality that raised the STOP flag for the application.

Keywords: Weeding machine performance, Middleware, ISOBUS, Implement Object Pool.

1. INTRODUCTION

Most of today's precision agriculture machinery are ISOBUS compliant since its role in conducting all the management techniques and actions from seeding to harvesting is very imperative. Although in a few other aspects of agriculture such as weeding applications with specialty crops or in viticulture such as spraying applications in vineyards, ISOBUS is not yet fully integrated. Especially, those applications in agriculture and viticulture require the utilization of small autonomous tractors and agricultural robots due to the field conditions. Besides that, the implementation of mobile robots assists in increasing the precision of the application, saving cost, and filling the gap in the scarcity of labor. Therefore, it is worthwhile to explore solutions for communication and compatibility issues between mobile robots and agricultural implements by integrating the ISO 11783 standards. This would allow farmers to control the interaction between the machine and the crop, in terms of evaluating the in-field machine performance in real time.

Wide use of mobile robots and autonomous vehicles in today's industrial as well as environmental applications can be found. However, in agricultural areas, there is still a strong tendency going on developing mobile robots and autonomous vehicles to improve efficiency in specific tasks such as the reduction of soil compaction and replacement of machine operators. Besides, mobile robots should overcome certain technical challenges such as planning and performing field tasks by considering constraints and unexpected obstacles during the operation (Dimitrios S. Paraforos et al., 2022). Technically, a full capacity of using mobile robots and autonomous vehicles in agriculture has not been achieved yet due to improper communication with up-to-date implements (Fountas et al., 2020). So, above all, better compatibility between the robotic platforms with the current agricultural implements and sensing systems applied in different areas of

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agriculture still remains a vital task for the research community.

Many breakthroughs and improvements have been achieved with the development of the ISOBUS network for connecting tractors with agricultural implements during the last 3 decades (Oksanen & Auernhammer, 2021). Therefore, there have been many research studies focusing on the latest implementation of ISOBUS on technologies (D.S. Paraforos et al., 2019) and assessing the performance of ISOBUS-compliant implements as well as improving the efficiency of agricultural operations (Sharipov et al., 2021) (Heiß et al., 2021). As the functionalities of ISOBUS for the implements has being regularly upgraded, the demands on increasing the capacity of the ISO11783 network are increasing as well. Regarding the enhancement of bus network performance, (Iglesias et al., 2014a) and (Iglesias et al., 2014b) presented methodologies for improving the network initialization by optimizing the compression and decompression of IOP files. Even though many progressive research studies have been carried out and the ISO 111783 standard is widely integrated with 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.

With the aim to integrate a commercially available robot with an existing mechanical weeder by leveraging ISO 11783 standards in the combination of software and hardware level, this work presents the development of middleware for the communication between the mobile robot and the mechanical weeder. The developed middleware is also responsible for the address-claiming procedure between the robot and the implement electronic control units (ECU). In addition to that, the development of an implement object pool for the representation of the weeder performance, in terms of weeding quality, and its integration with the simulated ECU of the weeder is discussed. Evaluation of the in-field weeding quality resulting from the Analytics software is discussed. The novel part of the present paper comes with the approach to using an industry standard such as the ISOBUS in connecting the mechanical weeder with advanced cognition capabilities forming a holistic and interoperable robotic system.

2. MATERIALS AND METHODS

2.1 Conceptual architecture for the communication

One of the important initial steps of the work was the development of the conceptual architecture for the integration of the robot with the weeding machine as well as for communication using the ISO11783 network (Fig. 1). The AGC Box is responsible to feed the middleware with the position data and the speed info. At the same time, the middleware simulates the TECU functionality of ISOBUS, therefore, the simulated TECU of the middleware is responsible for receiving those data from the AGC-Box, claiming the address with the ECU of the weeding machine and supplying the ECU of the weeding machine with the position and speed info. The architecture also shows the communication between the middleware and the Farming controller. The main function of the Farming controller is to record the machine's performance, in terms of the geolocated weeding quality, capacity of the machine as well as ground-based operation speed.

2.2 Instrumentation

The mechanical weeding machine that can be seen in Fig. 2a

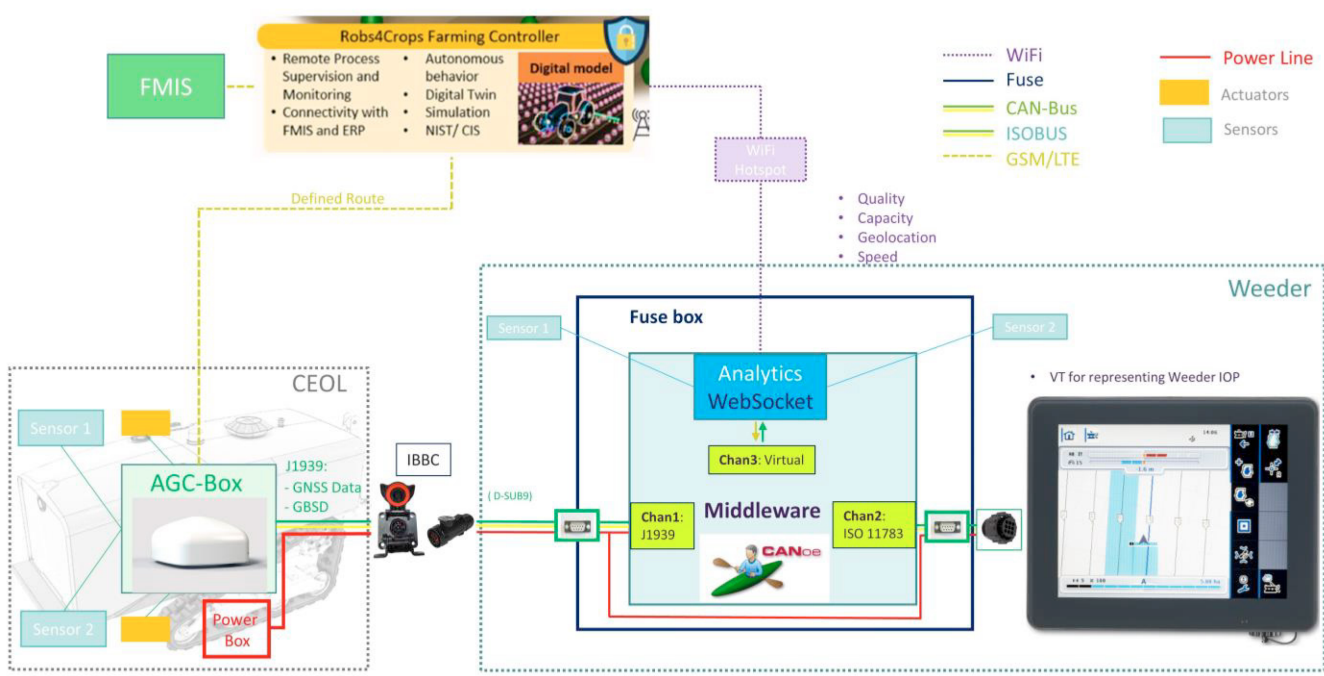

Figure 1. The conceptual architecture for the smart weeder connected to the CEOL robot.

was selected to be attached to the CEOL Robot (AgreenCulture, Toulouse, France) for carrying a weeding application in France. A roller for the weeding application and the ground-touch disc is attached to the main frame of the machine. The CEOL robot is equipped with a category 1 lifter that allows it to be adjusted to different farming equipment. Besides that, it is designed with a special frame that holds AGC-Box. The AGC-Box provides the robot with the position data as well as is responsible for guiding the robot. The device also acts as a real interface between the robot and the attached implement since it complies with controlled area network (CAN) standards. There is no stability issue in the real-time communication between the CAN network and the AGC-Box. So, the box is designed with CAN Bus that gives the users to integrate it with the standardized protocols of agricultural implements. The performance of the AGC-Box can be monitored and controlled from a distance using a mobile phone or tablet.

To assemble the PC for the middleware and analytics software and all other necessary hardware for the communication together, a metal Fuse-Box was developed (Fig. 2b). For the communication between the AGC-Box and the middleware, ISOBUS Break-Away Connector/Cables (IBBC) was implemented. The IBBC is connected to one of two channels of VN 1610 CAN Interface (2xCAN high-speed transceiver, Vector Informatik GmbH, Stuttgart, Germany) using Y-Cable (Vector Informatik GmbH, Stuttgart, Germany). Moreover, a High-performance rugged PC (Karbon 700-X2, OnLogic, USA) is fastened to the developed Fuse-Box to run the Middleware and Analytics software as well as to communicate with the external RGB cameras that feed the Analytics with the needed data. The PC is equipped with a Nvidia RTX 2080 Ti graphics card, Power Over Ethernet (PoE) PCI, built-in SIM, and 5G adapter. It runs Microsoft Windows 10, Python 3, OpenCV, Pytorch, and Python-CAN. In addition, there is a VPN installed that connects this computer to the whole network of Robots/Tractors.

2.3 Middleware

For the middleware, the CANoe v15 (Vector Informatik GmbH, Stuttgart, Germany) was chosen together with its ISO11783 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. The developed middleware has three network configurations (Channels) as shown in Fig. 3. The first network named J1939 is in charge of receiving the J1939 protocol-compliant messages, investigating the message compliance, and transferring them to the simulated TECU node of the second network (Fig. 3b). Subsequently, the second network characterizes the entire ISO11783 network for the complete setup (Fig. 3a). This mainly includes the simulated ECU of the weeding machine, the simulated TECU functionality of ISO11783 network, and the special network node for transferring a warning signal, in terms of emergency stop for the robot, coming from the analytics software. The simulated ECU of the implement designates an interaction layer of the ISO11783 network that copes with all the "Object Pool" elements of the developed interface for the VT based on the incoming signals from the Analytics software. This also includes communication with

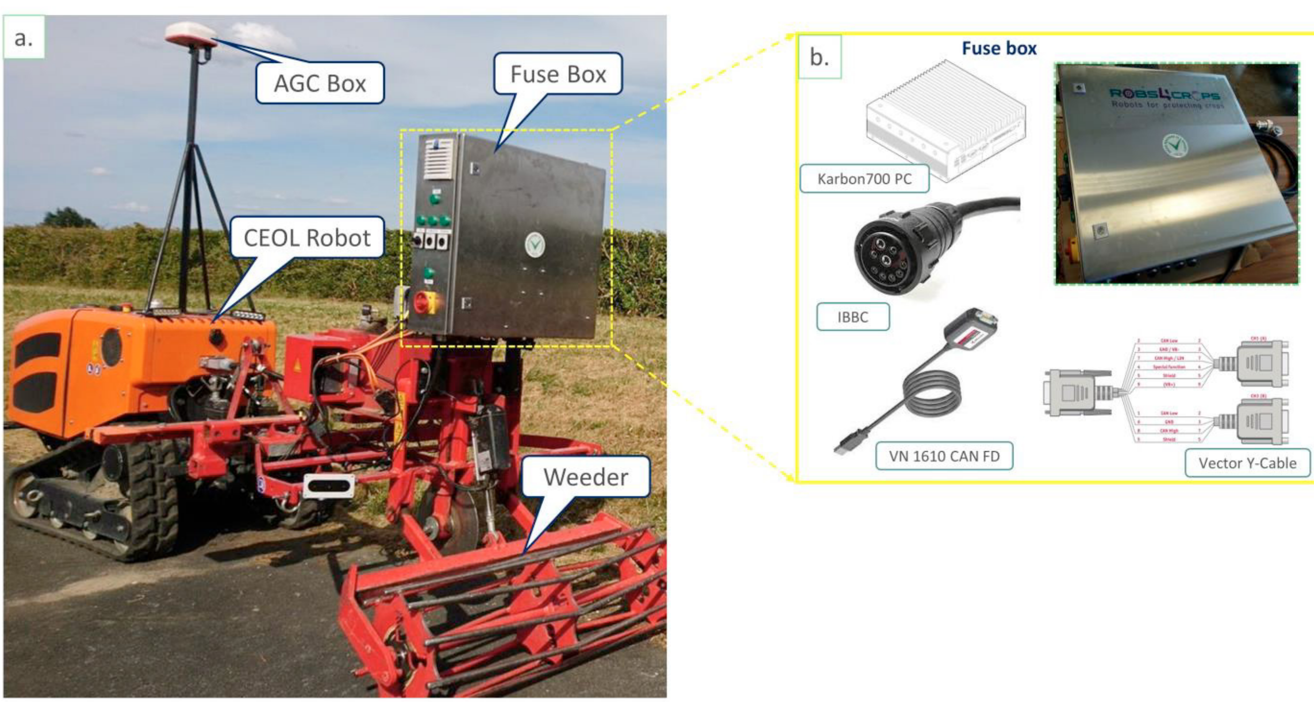

Figure 2. (a) Instrumentation for the "smart" weeding machine connected to the CEOL robot and (b) the developed Fuse-Box that unites the middleware PC with all the necessary hardware for communication.

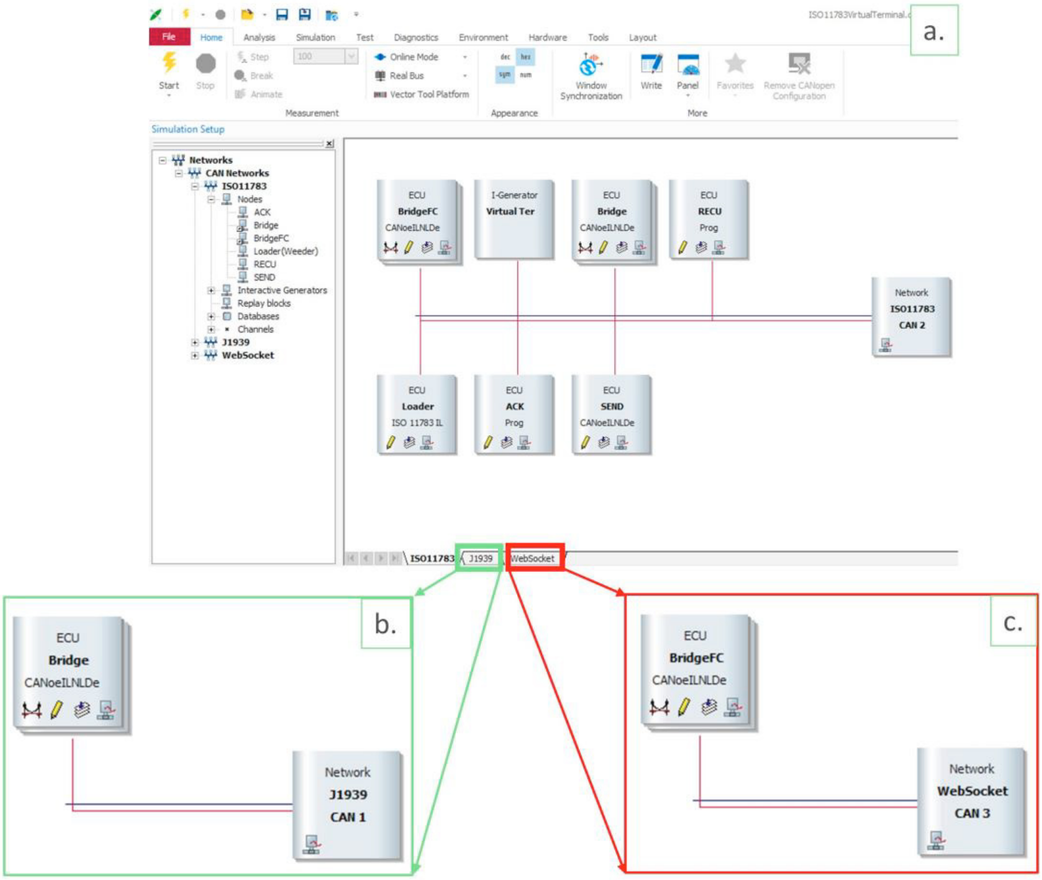

Figure 3. (a) Configuration of the Middleware for ISO11783 network (Chan2) of the "smart" weeding machine, (b) the configured bridge of the Middleware (Chan1) for incoming messages from the AGC-Box, and (c) the bridge of the middleware (VirtualChan3) for the WebSocket to communicate with Farming Controller.

the simulated TECU. Since the AGC-Box of the CEOL robot does not designate with the TECU functionality, the node of the ISO11783 network for the simulated TECU specifies the robot ECU (class 2) based on the ISO interaction layer to feed the implement ECU with the needed data. The specific tasks of the CAPL scripts are to properly introduce the incoming messages to the ISO11783 interaction layer, to set the necessary conditions on the signals, and to transmit the final messages to the requested channels. Finally, the third network of the middleware on channel 3 virtually introduces the WebSocket and the Analytics to the ISO11783 network. The main functions of the third network are to exchange as-applied information with the Farming Controller using the WebSocket and to communicate with the Analytics software.

2.4 Analytics

As shown in figure 2b, the Analytics runs on the Rugged PC to quantify and qualify the weeding quality. The PC has an integrated microcontroller that is used to control the turn off/on the computer when the CEOL robot finishes/starts work. The PC is powered by the CEOL using the signal pins from the IBBC, even if the CEOL robot abruptly turns off.

Through PoE, the computer is connected to two stereo cameras (OAK-D-PoE). The OAK-D-PoE is also a spatial Artificial Intelligence (AI) module that can run advanced neural networks simultaneously while providing depth from two stereo cameras and color information from a single 4K camera in the center. Since the data recorded from the cameras is not sufficient to properly assess the quality of weeding because of the cutting mechanism under the soil, the extra sensors such as ZF Toerental-sensor GS100701 and an encoder Joy-it COM-KY04ORE to measure the presence of the magnetic field and rotation were attached to define the blockage.

The algorithm that runs on the Analytics checks for the "heartbeat" of sensors every 100ms. When one of the sensors shows irregularity, a secondary timer is set and checks for how much the "heartbeat" wasn't heard. It immediately starts influencing the "quality" parameter, indicating something might be wrong. Even if the sensor is faulty or damaged, there are "zeros" or "ones" transmitted causing a plunge in the heartbeat. In this scenario, the Analytics regards it as a poor weeding quality. If the "heartbeat" of the specific tool is not heard for more than a specific time, the algorithm immediately starts logging in GPS to determine the distance that the robot has traversed and the time how much the sensor was not active. In this scenario, and based on the tool, this has a very high impact on penalizing the "quality". If the sensor is not specified for a significant amount of time, then the "error" signal is sent to the CEOL Robot for stopping the entire setup. When that happens, the camera feed is immediately sent to Farming Controller so the farmer can observe if the error is true-positive or false-positive. The "heartbeat" is a value that is calculated based on the sensor type and the probability of the sensor having irregularities (which is a factor extracted from the sensor website) and priority (in case many sensors are connected). This value is then directly connected to the quality of the weeding.

3. RESULTS AND DISCUSSIONS

3.1 Implement Object Pool for the VT

The middleware could aggregate and simulate all the ISOBUS functionalities as well as the ECU of the weeding machine. However, the IOP for the ISOBUS interface should be developed and linked with the system variables of the simulated ECU. The interface was developed using ISO-Designer software (Jetter AG, Ludwigsburg, Germany), shown in Fig. 4.

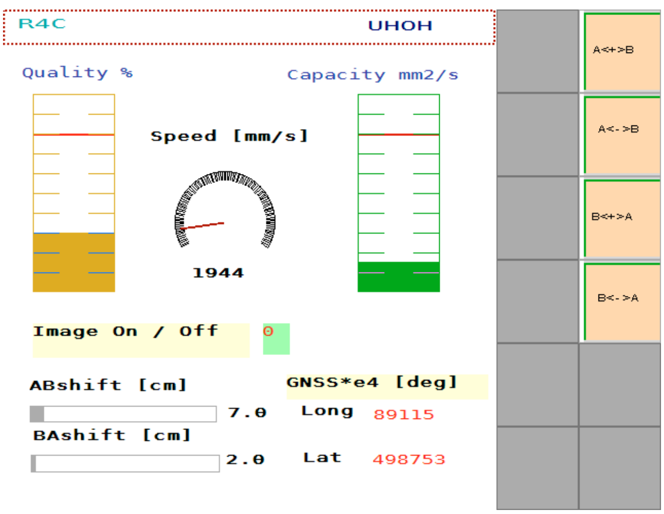

Figure 4. The developed interface (IOP) for the ISOBUS Virtual terminal.

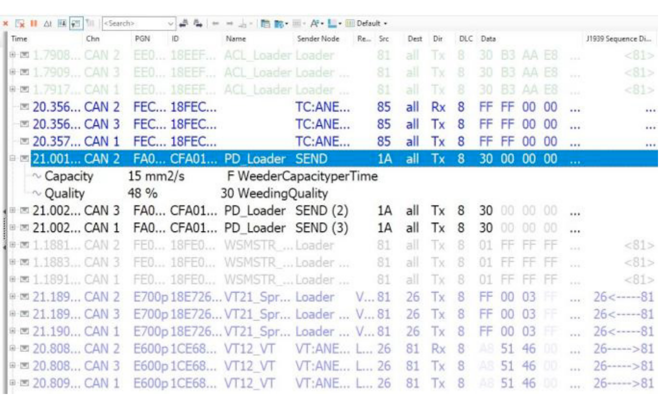

Figure 5. The real-time investigation of the data flow

All the included "object pool" components such as the data mask, key group, and working set are linked with the corresponding variables of the weeding machine ECU in the middleware. Thus, the operator can assess the performance parameter of the weeding machine such as the machine speed, the weeding quality, and the capacity in real-time. The latency of the setup, which is defined by the time of initial feeding the VT with the received messages from the Analytics, was approximately 0.93s. Besides that, the developed middleware has the feature of running the interface in simulation mode, while the same information is presented in the actual terminal with the UT functionality in Figure 5.

The smart weeder including all the above-described instrumentation 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 analyse the images/video stream from these cameras using AI (deep learning) models/algorithms. The model is embedded directly into the camera and only provides numerical values, in terms of the number of weeds detected via a specific API from the camera. 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 the ISO 11783 telegram protocol. The middleware stores this information to create a task file when the operation is over and also forwards it to the cloud-based farming controller, for the latter to update the digital twin variables in real-time. Figure 5 also represents the data stream for the entire setup. The highlighted area of the trace window for the data stream indicates the results of the weeding quality and the covered capacity of the machine.

3.2 Weeding Quality

The data recorded from all the external sensors on the weeding machine is processed on the Analytics software by applying the sequences described above in subsection 2.4.

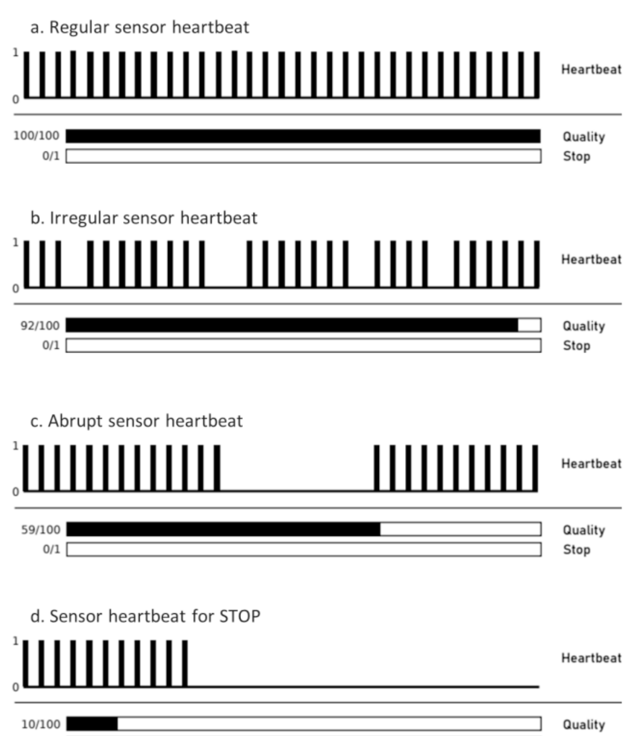

Figure 6. The quality evaluation for the scenario of (a) maximum with no stop signal, (b) slight impact with no stop, (c) significant impact close to receiving the stop signal, and (d) minimum quality with a received stop signal.

The results are interpreted for a simplified representation. Each heartbeat happens every 100ms, thus in the figures below it is a presentable approximation of the values. There were four main distinct patterns observed, which are coded in the state machine, as shown in Fig. 6.

As shown in Fig. 6a-d, the heartbeat has a direct impact on the quality of the weeding. When the Heartbeat is regular (Fig. 6a) the quality is 100%. This message is relayed constantly to Middleware and Farming Controller. Subsequently, the irregular behavior/pattern, when the disks spin (Fig. 6b). This mainly indicates that there is a slight decrease in the quality due to an occurrence of slippage. The next stage would be a significant abruption of the signal. In this state, the pattern, shown in Fig. 6c, is related to disc blockage for a specific time. When the blockage of the disc is eliminated, weeding goes back to normal condition. This state indicates how close the stop signals are to get triggering. The final state describes the pattern (Fig. 6d) that the quality of the weeding downgrades to 10% and the STOP flag is triggered.

6. CONCLUSIONS

The presented and described architecture of design for integrating the ISO11783 protocol into communication between the robot and mechanical weeder has been implemented and tested in farming conditions. The developed instrumentation that makes the implementation of the architecture possible was presented in detail.

The assessment of the results, in terms of processing the weeding quality on the Analytics based on four states of the weeder, indicated that the applied method is sufficient to evaluate the weeder performance at this stage of the work. The achieved results of the work would play an essential role in further steps to include more process-related information in order to optimize the performance of the vehicle-implement combination.

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