Programmable logic controller applied to operational functions in agricultural implement based on ISO 11783 standard

Controlador lógico programável aplicado às funções operacionais de um implemento agrícola baseado na norma ISO 11783

ABSTRACT
ISO 11783 standard is supported by the Agricultural Industry Electronics Foundation (AEF) with the aim to promote the compatibility between agricultural products from different manufacturers. Several studies have been used it to develop automation for tractor-implement in industry. The main objective of this paper is to describe an application of ISO 11783 standard for a sprayer with the implementation of a Programmable Logic Controller (PLC). PLC was used as an electronic control unit to provide the integration between the sprayer control and the operator-user by means a universal terminal installed on a tractor. The ISOAgLib was used due its compatibility with the standard. The elements of the universal terminal were designed according to the ISO 11783 standard for agricultural operations of a sprayer. Some essential programming routines and computational tools were implemented based on the ISO 11783 standard that allowed its implementation for an agricultural application.

Keywords: Embedded electronics; ISOBUS; sprayer

RESUMO

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A norma ISO 11783 é apoiada pela AEF (Agricultural Industry Electronics Foundation) com a finalidade de promover a compatibilidade entre os produtos agrícolas de diferentes fabricantes. Diversos estudos estão utilizando esta norma para o desenvolvimento da automação trator-implemento na indústria. O principal objetivo deste artigo é descrever uma aplicação da norma ISO 11783 para um pulverizador com a implementação de um controlador lógico programável (CLP). O CLP foi utilizado como uma unidade de controle eletrônica para promover a integração entre o controle do pulverizador e o operador-usuário por meio de um terminal universal instalado em um trator. A ISOAgLib foi utilizada devido à sua compatibilidade com a norma. Os elementos do terminal universal foram elaborados de acordo com a norma ISO 11783 para as operações agrícolas de um pulverizador. Algumas rotinas essenciais de programação e ferramentas computacionais foram implementadas com base na norma ISO 11783, permitindo a sua implementação para uma aplicação agrícola.

**Palavras-chave:** Eletrônica embarcada; ISOBUS; pulverizador

1 INTRODUCTION

The ISO 11783 standard establishes some parameters for communication between the ECU (Electronic Control Unit) in agricultural machinery and implements. 14 documents formed this standard, such as ISO 11783-6:2018 that describes a universal terminal (UT) as the capability of operating an implement on any terminal at the same time; also, the capability of using one terminal for operating different implements. The main function of the UT is to display the user interface of the ECU. NBR ISO 11783-6: 2017, a technical Brazilian standard, also describes the UT.

The ISOAgLib programming library (Spangler and Wodok, 2010) contains all functions related to the ISO 11783 standard as well as the established machine interfaces implemented. A working set (WS) is shown to the operator on the graphical display using display areas that are defined by data masks, alarm masks and soft key masks.

According to Backman et al. (2013) electronics components have been added on tractors over the years and nowadays the devices are able to communicate with another through a common interface (ISO 11783 standard). Suomi and Oksanen (2015) developed an electronic control system compatible with ISO 11783 standard to control working depth for a seed drill, it was found that the sowing depth was 1.7 mm shallower compared with the working depth on average. Oksanen et al. (2015) proposed a remote access of ISO 11783 for telematics applications for agricultural machinery. The system was useful for transferring few data variables from a tractor and a connected seed drill.

Batbayar et al. (2019) simulated an UT and implemented it on the sprayer, the manure spreader and the global positioning system modules were also implemented with the PCAN-USB device in order to analyze all CAN (Controller area network) messages and protocols according to the ISO 11783 standard. Siponen et al. (2020) developed a tractor-implement automation based on modelling and simulation according to the ISO 11783 standard to the next-generation of equipment. Paraforos
et al. (2019) cited this standard for systems focused on decision-making or process monitoring, some examples are guidance and control; data acquisition and transfer; and data management and analytics.

For Brazilian agricultural conditions ISO 11783 standard is not yet consolidated, so studies related to develop applications with this standard is helpful to promote the integration between the agricultural implement and the embedded electronics to insert the country in this innovation process. The objective of this paper is to describe an integration of ISO 11783 standard for a sprayer with the implementation of a PLC.

2 MATERIAL AND METHODS

The activities were conducted at Lanapre (National Reference Laboratory in Precision Agriculture) which belongs to Brazilian Agricultural Research Corporation (Embrapa) in São Carlos, SP, Brazil. Activities were developed in order to control the bar sections of the sprayer and its activation automatically using a PLC, Ladder language in MasterTool IEC 1.10 (Altus S.A.) software, by the RS232 communication.

PLC operated as an interface among the processing available on the ECU and the screen displayed on the universal terminal for activating the sprayer sections through the communication established by the PCAN-USB device. PCAN-USB device was used to analyze CAN messages and network protocols (transport protocol – TP; extended transport protocol - ETP) and to request parameter group number (PGN) messages. Each message in CAN network is preceded by an identifier that is unique to the transmitting controller (Tumenjargal et al., 2013). PLC is commonly used for agricultural applications, such as precision irrigation systems (Işık et al., 2017).

The UT stored the display in the object pool (OP), a representation of a WS that consists of objects supported by the standard. The objects may be input numbers, output numbers, polygon graphics or bitmap graphics and it have parameters such as position, size, color and value. As soon as the WS is connected to the network and powered up, the UT and WS start to communicate (Tumenjargal et al., 2013).

The IsoAgLib 2.6.x open-source library (OSB AG) was implemented in a Linux operating system environment due its accessibility for the hardware adaptation. The display screens were created on VT-Designer 1.2.0 software (OSB AG) to enable sprayer functions to be performed by the logic ports of the PLC according to the ISO 11783 standard. The programming was developed and compiled in the Eclipse 4.3 (The Eclipse Foundation), an IDE (Integrated Development Environment), to generate the ecuDisplay which is an executable file that runs on the ECU of the implement according to the requirements of the standard. GCC compiler (Free Software Foundation) was based on C/C++ language.
A tractor (110.32 W; 150 cv) compatible with the standard provided the required power to activate the hydraulic system of the sprayer (Jacto S. A., Advance 3000). The sprayer, commonly used for annual crops, had a tank capacity of 3,000 liters with electrical section activation and allows variable rate applications. The spray nozzles were spaced 0.50 m apart on the spray bar and made of ceramic material with the jet as fan shaped (110° for maximum pressure). The rotation of 1,050 rpm and 280 rpm in the power take-off (PTO) was maintained in the tractor. The equipment used to develop the proposal application are shown in Table 1.

Table 1. Equipment used to control the sprayer according to the ISO 11783 standard

| Equipment       | Manufacturer      | Model         | Function                                                                 |
|-----------------|-------------------|---------------|--------------------------------------------------------------------------|
| PLC             | Altus S.A.        | DUO351        | Programmed in Ladder language for sprayer control                        |
| NUC             | Intel             | Linux 32 bits | IsoAgLib library implementation                                          |
| Universal terminal | AGCO             | GTA-Console II| User interface for sprayer control                                       |
| PCAN-USB        | Peak              | IPEH-002021   | USB-Serial connection to transfer CAN messages                           |
| Relay           | Tianbo            | 30 A–14 V     | Activate sprayer functions via PLC                                        |

PLC: Programmable Logic Controller; NUC: Next Unit of Computing; CAN: Controller Area Network

The PLC was configured via MODBUS RTU messages using a baud rate of 9600; 8 data bits; no parity; delay of 5 ms; 2 stop bits. The relays activated the sprayer functions according to the PLC commands and switched the solenoid valves between 0 and 12 V. Figure 1 is an overview of the main components used to develop the proposed application.
The sensors allocated on the sprayer and its specifications are described in Table 2. Such sensors sent information in the form of pulses (digital) or analogical to control the sprayer sections via PLC. The operator-user can view the actual condition of the sensors and command manually the actuators through the universal terminal installed on the tractor.

**Table 2. Specifications of the sensors on the sprayer**

| Category     | Sensors     | Manufacturer   | Specifications                  | Function                                      |
|--------------|-------------|----------------|---------------------------------|-----------------------------------------------|
| Inductive    | Speed       | Pepperl Fuchs  | 20 pulses spin⁻¹                | Calculates average speed of the sprayer       |
|              |             |                | 10-30 V*                        |                                               |
| Pulsed       | Flow rate   | Polmac         | 600 pulses L⁻¹                  | Provides the flow into sprayer system         |
|              |             |                | 12 V*                           |                                               |
| Switch       | Liquid level| Jacto S.A.     | 10-30 V*                        | Indicates if liquid level is below 250 L      |
| Analogical   | Pressure    | Wika           | 0-350 psi                       | Indicates the pressure into sprayer system    |
|              |             |                | 10-30 V*                        |                                               |

*: represents the power supply of the sensors

A resistor of 10 kΩ (pull-up) was inserted between the positive and the signal of the flow rate sensor, due to its NPN type output in the form of pulses, in order to allow that its signal could be read by the PLC. The speed of the sprayer was calculated as a function of counting the number of holes during wheel spin using inductive sensors installed on the left and right wheels (radius of 0.688 m) of the implement. These sensors started the counting independently every two seconds, its values were used to calculate an average \( C_M \) in order to obtain the average speed of the sprayer.

A resistor of 1 kΩ (pull-up) was insert between the positive and the signal of these sensors to enable its reading by the PLC. The average speed of the sprayer was calculated according to the Equation 1, based on the values indicated by the sensors allocated on the wheels.

\[
S_M = 0.194535 \times C_M
\]  

where: \( S_M = \) average speed of the sprayer (km h⁻¹); \( C_M = \) average counting of the wheels.

If the tank volume of the sprayer was below 250 liters the liquid level signal was transmitted to a digital input of the PLC that turned off the sprayer sections. The pressure sensors, with analogical readings between 0 and 350 psi, represented by voltages of 0 and 5 V, respectively, sent the information to a solenoid valve, which directs the liquid to the tank (return position) if the pressure exceeds the value of 45 psi, or to the sections to continue spraying (work position).
The solenoid valves control consists of four segments, each of which has three extensions, using a motor driven of 12 V, switching to terminals A and B, i.e. solenoid valves were opened with GND (ground) in A and 12 V in B; and closed with 12 V in A and GND in B. The PLC outputs were connected to 12 solenoid valves to turn on/off the sprayer sections.

A pressure regulator was used to increase or to decrease the pressure on the system and a relief solenoid valve to direct the liquid to the sprayer sections or to the tank (depending on the pressure of the system). The actuation time of the pressure regulator was 15 s, reversing the polarity to increase or decrease the pressure on the system.

The spraying operation could happen in manual or automatic by means of the PLC connected to the relays, since the relief solenoid valve was set in the work position and the pressure regulator in the return position.

Figure 2 shows the main actuators and a pressure sensor on the sprayer.

![Figure 2. Components of the sprayer actuators and the pressure sensors](image)

The amount of liquid verified by the flow rate sensor at each pulse was 1.667 ml (0.001667 l), so the actual flow rate ($q_a$) was compared every two seconds to the control flow rate ($q_c$), which was obtained according to the Equation 2. The inputs were the required flow rate ($Q$) and the length of the spray bar ($f$), both indicated by the operator-user through the PLC keyboard.

$$q_c = \frac{Q \times S_M \times f}{600}$$

where: $Q$ = required flow rate (L ha$^{-1}$); $S_M$ = average speed of the sprayer (km h$^{-1}$); $f$ = length of the spray bar (m).

If the $q_c$ was greater than the $q_a$, the pressure on the system was increased by the pressure regulator. If the flow rate, actual and control, were equal the pressure decreased. The control flow rate also was verified to avoid that the pressure exceeded that recommended by the manufacturer of the spray nozzles.
The activation of the spray bars was possible through electronic controls through PLC, with the activation visually monitored, i.e. the height of the spray bars was adjusted according to the agricultural application on the field for each crop. A function block (SFCActionControl) was used to initiate the opening and closing cycle of the spray bars that allows an input to be triggered during a time interval defined by the operator. In this case, due to the security reasons, the closing cycle only occurred if the open cycle was completed. The relation between the IsoAgLib data type (an input or an output of the PLC) and its function associated to the sprayer is described in Table 3.

Table 3. The relation between the IsoAgLib data type and its function

| Quantity (input/output) | IsoAgLib (data type) | Function |
|-------------------------|----------------------|----------|
| 14                      | Boolean              | 12 solenoid valves |
| 2                       | Relief solenoid valves |
| Level of the tank       |                      |
| Flow rate               |                      |
| Speed                   |                      |
| Pressure                |                      |
| 6                       | Numerical            | Level of the tank |
|                         |                      |
|                         |                      |

3 RESULTS AND DISCUSSION

Table 4 describes the relationship between the actual flow rate and the pressure in the spray nozzles. The equations of each nozzle indicate the output flow rate that should be compared to the value read by the sensor to verify if the pressure on the system should be regulated.

Table 4. Equations to indicate the output flow rate for each spray nozzle

| ID | Spray nozzles | Section | Pressure (psi) | Flow rate (L min⁻¹) | Equation |
|----|---------------|---------|----------------|----------------------|----------|
| A  | AXI 110 04    | 1       | 15-45          | 0.96 - 1.62          | 0.96 + 0.022(x - 15) |
| B  | ADI 110 01    | 2       | 15-60          | 0.25 - 0.52          | 0.25 + 0.006(x - 15) |
| C  | AXI 110 02    | 3       | 15-45          | 0.51 - 0.84          | 0.51 + 0.011(x - 15) |

ID: identification; x: average pressure

The sprayer section was performed according to the nozzle output flow which is a function of the pressure on the system and considered as linear (Figure 3). The maximum pressure nozzle was verified for 45 psi, so the section command programmed in the PLC must meet this condition. PLC was used due its capacity to manage variables according to its actual condition. Barkhordari et al. (2020) described the automatic control systems as a manner of reducing operational losses in agriculture.
The maximum application rate of 2.98 L min\(^{-1}\) was found when the sprayer operates in 45 psi. The combinations indicated that each nozzle could be triggered, i.e. the combination 0 corresponds to all sections switched off and the combination 7 to all sections connected (Figure 4).

Table 5 describes all the combinations that allows the user interaction in manual mode using the universal terminal by setting the states of actuation for each sprayer bar section. This application can be useful to the site-specific control of spraying (Tona et al., 2018). Bauer et al. (2019) created crop protection maps from thank level information (average rates) using a rounding filter on CAN messages.
Table 5. Manually actuation states of the sprayer

| Actuation states | Conditions | Operation |
|------------------|------------|-----------|
| 0                | 0          | Turn off all sections |
| 1                | 0 < \(q_c\) ≤ B | Active section 1 |
| 2                | B < \(q_c\) ≤ C | Active section 2 |
| 3                | C < \(q_c\) ≤ B+C | Active sections 1 and 2 |
| 4                | B+C < \(q_c\) ≤ A | Active section 2 |
| 5                | A < \(q_c\) ≤ A+B | Active sections 1 and 3 |
| 6                | A+B < \(q_c\) ≤ A+C | Active sections 2 and 3 |
| 7                | A+C < \(q_c\) ≤ A+B+C | Active all sections |
|                 | A+B+C < \(q_c\) | Alarm |

\(q_c\): actual flow rate; A: flow rate of the spray nozzles A; B: flow rate of the spray nozzles B; C: flow rate of the spray nozzles C

Figure 5 summarizes the main steps performed to develop the integration between the ISO 11783 standard and its application for a sprayer. Batbayar et al. (2019) developed a similar hardware implementation for multiple modules on a tractor.

![Development of an implemented ECU with the universal terminal](image)

**Figure 5.** Development of an implemented ECU with the universal terminal

The screens designed (Figure 6) according to the ISO 11783 standard for the universal terminal implementation shows some sprayer functions and allows the operator-user used it to activate the spray bars, control the distance of the bars from the ground and assessing the agricultural operation at the field. The keys on the display also allow the operator-user to view the current status of the signal from the sensors, such as the average speed, pressure, flow rate and liquid level available on the sprayer. The graphic display has a limited set of graphical objects, but operators can navigate into it and manipulate the values. Kortenbruck et al. (2017) developed a display on a UT to generate machinery operation profiles to the user-view through ISO 11783 standard. This kind of approach
could, potentially, support some agricultural facilities for production systems, as described by Yang et al. (2020).

![System for sprayer control: user interface](image)

**Figure 6.** User interface for sprayer control implemented on the universal terminal

**4 CONCLUSIONS**

A methodology for the sprayer activation and its sections control automatically was developed according to the ISO 11783 standard. The resources of embedded electronics, programming routines and computational tools were implemented based on this standard, which supported the communication between the operator-user and the equipment features, including the automatic control of the bar sections. A universal terminal was designed and implemented on a tractor to enable typical agricultural applications of the sprayer according to the requirements of the ISO 11783 standard.

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