Design and Implementation of a Mobile Agricultural Robot for Remote Sensing Applications

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ABSTRACT

The number of electronic devices connected to agricultural machinery is increasing to support new agricultural tasks related to the Precision Agriculture such as remote sensing and spatial variability mapping. Based on the necessity of projecting more automated agricultural machines and implements, a current trend in the agricultural area is the development of mobile robots and autonomous vehicles. These robots and vehicles developed with the same technologies existing in agricultural machinery can be more efficient doing specific tasks than traditional large tractors, giving the same, or even greater, overall output as conventional systems. One of the major challenges in the design of these robots is the development of the electronic architecture for the integration and control of the several devices related to the motion, navigation, data acquisition and communication (or teleoperation) systems. A technology that has strong potential to be applied on the devices interconnection in agricultural machinery is the CAN protocol. This technology provides significant benefits and has been used as an embedded control network in agricultural robots and vehicles. The implementation of the ISO11783 (ISOBUS) standard represents the standardization of the CAN protocol for application in agricultural machinery. This work describes the design and implementation of a mobile agricultural robot for remote sensing applications. The discussions are focused on the developed electronic architecture, the wireless communication system for teleoperation and the distributed control based on CAN protocol and ISO11783 for the mobile agricultural robot. The evaluation of the developed system was based on the analysis of the performance parameters obtained with the robot operation. The results show that the developed systems meet the design requirements for an accurate robot movement and an acceptable response time for control commands and supervision. It is expected that this paper can also support the development of mobile agricultural robots and CAN and ISO11783 based distributed control technologies.

Keywords: Mobile agricultural robots, CAN protocol, ISO11783, remote sensing, teleoperation, distributed control.

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1. INTRODUCTION

An increase in the application of the automation and informatics in the agricultural area can be observed in recent times. New agricultural practices, related to the Precision Agriculture, have enhanced the importance in the research of embedded sensors and communication networks (Auernhammer and Speckman, 2006) for the study of spatial variability and remote sensing applications. A certain degree of automation is necessary for the use of these new practices that depends on some recent technologies only adapted for the agricultural area such as the case of the global positioning systems, geographic information systems and the interconnection of devices and controllers used in the agricultural machinery (Oksanem et al., 2004). New technologies and devices for real-time data acquisition and actuation have been released to equip agricultural machineries to support these practices and automated them (Auernhammer, 2004). A strong tendency is development of mobile robots and autonomous vehicles for application in specific tasks, improving the efficiency and giving better results (soil compactation reduction and machine operator absence) when compared with the use of traditional large tractors and implements(Blackmore and Griepentrog, 2006).

Autonomous vehicles and mobile robots have been widely used in industrial production and warehouses, where a controlled environment can be guaranteed. In agriculture areas, research into driverless vehicles has always been a dream but serious researches started in the early 1960's (Blackmore et al., 2005). In recent years, the development of these vehicles has experienced increased interest. This development has led many researchers to start developing more rational and adaptable vehicles. These vehicles should be capable of working 24 hours a day all year round, in most weather conditions and have the intelligence embedded within them to behave sensibly in a semi-natural environment over long periods of time, unattended, while carrying out a useful task (Pedersen et al., 2005).

In scientific literature can be find studies that seek to adapt business agricultural machinery to make agricultural platforms (autonomous vehicles or mobile robots) as can be seen in Reid et al. (2000) and Keicher and Seufert (2000). A more recent trend is the development of platforms built specifically for agricultural autonomous vehicles or robots as can be seen in Åstrand and Baerveldt (2002), and Bak and Jakobsen (2004). However, the development of these platforms presents two challenges (Blackmore et al., 2004): developing a physical structure suitable for the agricultural environment, and develop an electronic architecture to integrate the various electronic devices. An electronic architecture must be robust and reliable, provide quick and ease maintenance and have modularity and flexibility to allow future expansions and connections of new equipments. allowing future expansions through the addition of new devices. Recent applications of mobile robots have used distributed architectures based on fieldbus networks to meet these requirements.

Fieldbus based control systems have replaced the traditional centralized control systems because of several benefits such as reduced cost and amount of wiring, increased reliability and interoperability, improved capacity for system reconfiguration and ease of maintenance (Moyne and Tilbury, 2007). Although the fieldbus distributed control systems offers several advantages over traditional centralized control systems, the existence of communication networks make the design and implementation of these solutions more complex. Networked control systems impose additional problems inherent in control applications that are usually difficult to meet due to the variations and uncertainties introduced by the fieldbus: delays, jitter, bandwidth limitations and packet losses (Baillieul and Antsaklis, 2007).

Between the several fieldbus, a technology that is widespread to be applied on these devices interconnection is the distributed communication based on the Controller Area network (CAN) protocol. In the agriculture area, the chosen of the CAN protocol (Bosch, 2006) as communication network due to its low cost of development and large acceptance and success for embedded electronics in the automotive area. The use of CAN in the agricultural area is confirmed in Suvinen and Saarilahti (2006) and its application to autonomous vehicles and mobile robots is presented in Nagasaka et al., (2004) and Darr; Stombaugh and Shearer (2005). The implementation of the ISO11783 standard, also called ISOBUS, represents the standardization of the CAN protocol to the agricultural area and constitutes the main target of development as described in Benneweiss (2005).

Following this guideline, this paper describes the design and implementation of a teleoperated distributed control system based on CAN protocol for a mobile agricultural robot. The Wireless Ethernet to fieldbus architecture is detailed presented and the distributed robot control over the CAN network is designed and discussed. Performance parameters such as motors response and architecture time delay obtained with the robot operation allows verify that the developed teleoperated architecture can be applied to distributed control of agricultural mobile robots using the CAN protocol with the ISO11783 standard.

2. DESIGN OF THE MOBILE ROBOT

2.1 Mechanical Structure of the Robot

The agricultural mobile robot was designed to be used as an experimental platform for development of control, navigation and data acquisition technologies to the agricultural area. The major application of the robot is to do the remote sensing of agronomic parameters of most important Brazilian culture in large areas. It doesn’t require actions that demand high power, as in agricultural operations, but only moving efficiently in this environment.

The mechanical structure, showed in Figure 1, was designed by the studying of work conditions required in field and desired characteristics of the project. It was established that the structure should be in *portico* with 2m of height and 2,5m of length, capable of operating in cultures up to 1.5 m of height, with adjustable gauge (width of 1,5 to 2,5m) to operate in various row spacing cultivation. To accomplish this, the system was designed in independent modules (side frame – number 1 and top frame – number 8 in Figure 1), together by telescopic bars (number 10), to meet the maximum possible situations.

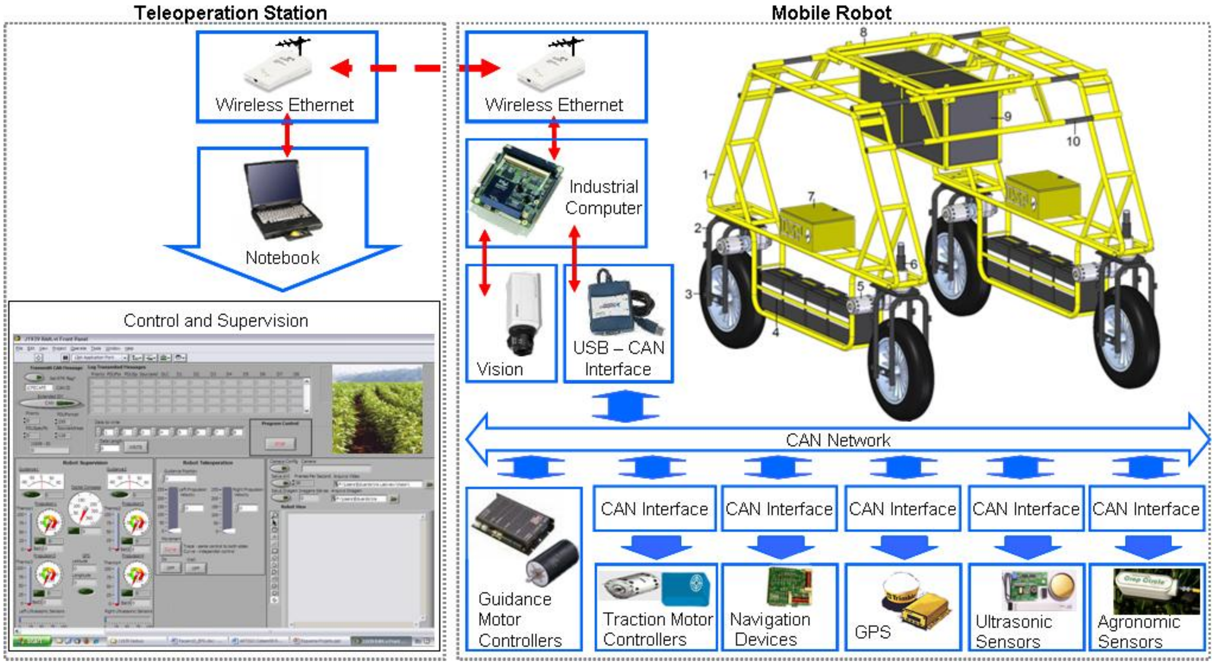

Figure 1. Architecture of the Agriculture Mobile Robot

The steering module (number 6), the propulsion module (number 5) and central box (number 9) complete the system. The structure also should be light and flexible compared with commercial agricultural vehicles, with the possibility to insert new sensors and actuators. The side boxes (number 7) contain the electronic systems to communicate with the CAN fieldbus and the motor controllers and also protect these devices from weather, dusty and vibrations. It is important to observe that heavier items in the robot such as batteries (number 4), propulsion and steering systems and side boxes are at least one meter of the soil, contributing to lower structure center of gravity, increasing its stability on sloping land.

The robot architecture with distributed CAN fieldbus was designed symmetrically between right and left sides of the structure, which allows the homogenous distribution of weight, simplifies the development, reduces design time and costs and the amount of cables, and accomplishes the maintenance of equipments installed in the system.

2.2 Electronic Systems and CAN-Based Electronic Control Units

The propulsion system of the robot needs to have accuracy in direction, low power consumption and low cost. Propulsion systems with wheels are cheap and, in function of the low need for traction and load to be distributed, meet the needs of this project. In this project, we adopted a four wheels system (number 3 in Figure 1) and to increase the ability of vehicle pull in adverse conditions, we adopted independent traction in each wheel. Each propulsion system is composed by a Roboteq AX2850 controller, a Bosch GPA 750W 24V DC motor, a 75:1 reduction system (25:1 of a planetary gearhead plus a 3:1 crown, pinion, chain transmission) and a Hohner Serie 75 incremental encoder with 100 pulses per revolution.

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Among the steering systems found, there are differential steering, articulated steering and wheel steering. Differential steering works by the difference between the speed of rotation of right and left wheels. In function of structure configuration is in portico format and with adjustable gauge, it was chosen a system that could be independent for each wheel, with easy construction and accuracy of steering, so we opted by the system Ackerman in front wheels. Each steering system is composed by a Maxon Motor kit (EPOS 70\10 positioning controller with CAN interface, a RE40 150W 48V DC motor with a 230:1 reduction planetary gearhead GP22C and MR incremental encoder with 500 pulses per revolution). However until the conclusion of this paper, the integration of the EPOS steering motor controllers in the CAN fieldbus is not finished. Because of this, the first operation tests are done with differential steering system for the mobile robot.

For integration (communication by the network, information exchange and control) between electronic devices, it was deployed a CAN fieldbus network based on ISO11783 protocol in the agricultural mobile robot. An electronic control unit (ECU), or CAN interface, develop in our laboratory (Sousa, 2002) was used for this devices integration. The Figure 2 presents the schematic diagram of a standard ECU with CAN communications capabilities.

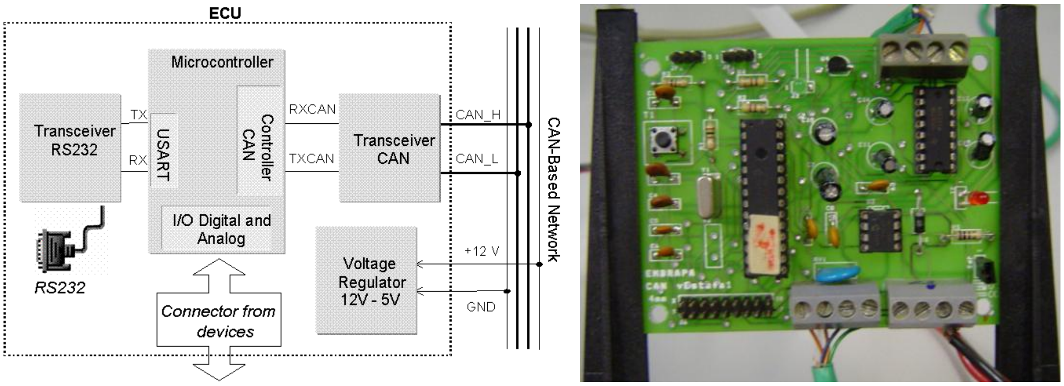


Figure 2. Schematic diagram and Front View of ECU CAN (SOUSA, 2002)

Figure 2 show that the ECU has three main components: the microcontroller, the CAN and the RS232 transceiver. The microcontroller used was the PIC18F258. This chip provides the logic operations for the CAN protocol communication and implements the programs for data acquisition of the devices connected to the I/O ports, such as sensors and actuators. A MCP2551 transceiver was incorporated into the ECU to provide switching between the digital TTL logic of the microcontroller and the differential output required on the CAN bus. And a MAX232 transceiver provides switching between the TTL logic and the output required by the serial RS232 port. To communicate in agreement to the ISO11783 standard, a microcontroller library was develop and inserted in the ECU. This microcontroller library is according to the specifications of parts 1 to 11 of ISOBUS documents. The implementation of the high-level ISOBUS functions (initialization, management and communication) was in C language and used as a basis a J1939 library for the Microchip microcontroller.

The CAN network developed not only enables the integration of sensors, actuators and computer systems relative with tasks of navigation (motor controllers, DGPS Trimble AG-114 and digital compass Vector 2X), but also enables the devices integration related to data acquisition of

agronomical variables, which will eventually compose the architecture of the robot. Until the moment, we used ultrasonic sensors (Polaroid 6500) and an active reflectance sensor (Crop Circle ACS-210) for information correlation with agronomical variables. The agronomical information acquired with the mobile robot georeference (latitude and longitude coordinates of the DGPS) allows building spatial variability maps.
In the architecture developed, the mobile robot is teleoperated. A teleoperation station showed in Figure 1, has the function of managing the operations performed by the robot, permitting planning, controlling and monitoring tasks in real-time via a Wireless Ethernet network based on IEEE 802.11 performed through a VNC connection. A directional antenna in both systems (teleoperation station and robot) allows the data communication and teleoperation up to 5 km of distance.

3. TELEOPERATION SYSTEM OF THE MOBILE ROBOT

3.1 Description of the Distributed Control System

Figure 3 presents the flowchart of the distributed control in the mobile robot. According to the flowchart, the user cans teleoperated the robot by selecting between two control methods. Sending manual commands or setting predefined commands to control the mobile robot. The predefined commands do not allow autonomous navigation only defined trajectories (for example walk in straight-line, do curves of user defined degrees) that simplify the necessary user commands to be sent to the robot. All commands defined by the user are transmitted to the mobile robot via a wireless digital link based on IEEE 802.11 standard performed by a VNC connection. The industrial computer in the mobile robot functions like a gateway. All information received via wireless link is transmitted into messages in the CAN network and vice-versa. The industrial computer is responsible too for the vision acquisition of the camera in the mobile robot.

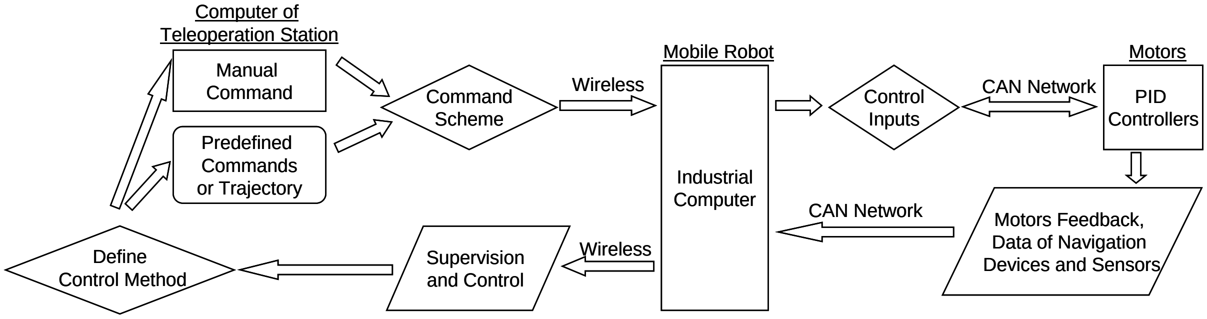


Figure 3. Control Flowchart of the Mobile Robot

The defined commands received via wireless are translated in control inputs for the motor controllers of the mobile robot. These control inputs are transmitted into messages in the CAN network. The ECUs in the robot receive the CAN messages with the control inputs and act in the motor controllers. The motor controllers use discrete-time PID controllers to control the robot motion. The motors feedback (encoder information about traction speed and steering position) and the data from other devices and sensors connected in the robot are transmitted too via the CAN bus to the industrial computer. And this information is sent back via wireless to the computer in the teleoperation station and is presented in the supervision and control software. Using the information about the robot, the user can decide how to actuate and control the robot movement, finishing the flowchart of the robot distributed control.

Experiments were done to design and define the PID controller gains for the motors control (speed control for propulsion motors) of the mobile robot. The PID controllers for speed control uses a sampling time of 16ms and were defined with the same gains (P=2, I=1.5 and D=1) because the four propulsion systems have the same equipment. The gains of the PID controllers are defined to achieve a suitable operation of the robot movement. The PID controllers for the traction motors need a soft start (speed increases like a ramp) because the high current demanded for the motors startup (the DC motors used in the robot propulsion have 750W and can demand up to 100A in startup if no soft startup is used).

3.1 Design of the CAN-Based Network

As described in Johansson, Torngren and Nielsen (2005), in CAN-based networks data are transmitted and received using message frames that carry data from a transmitting node to one or more receiving nodes. An identifier, unique throughout the network, labels each message of the node and its value defines the priority of the message to access the network. The CAN protocol is optimized for short messages and uses a CSMA/CD with NDBA (Carrier Sense Multiple Access / Collision Detection with Non-Destructive Bitwise Arbitration) arbitration access method. A node that needs to transmit a message waits until the bus is free and then starts to send the identifier of its message bit by bit. Bus access conflicts are solved during transmission by an arbitration process at the bit level of the arbitration field, which is the initial part of each frame. The bit stream of a transmission is synchronized on the start bit, and the arbitration is performed on the following message identifier, in which a logic zero is dominant over a logic one. CAN protocol support two message frame formats: standard CAN (version 2.0A, 11-bit identifier) and extended CAN (version 2.0B, 29-bit identifier).

The ISO11783 standard is based on CAN protocol, which has been used for a long time in the agricultural industry (Benneweiss, 2005). ISO 11783 is composed of 14 different parts that are based on the OSI (Open System Interconnect model). The physical and data link layers are based on CAN 2.0b protocol. CAN 2.0b specify the length of message identifier to 29 bits and the length of message data to 64 bits. The data bus speed is 250 kbit/s. Information is encoded in the CAN identifier (source address, destination address and data contents), whereby two Protocol Data Units (PDU) are differentiated: PDU1 and PDU2 as shown in Figure 4. PDU1 format allows for peer-to-peer communication, and the PDU2 format for broadcast communication.

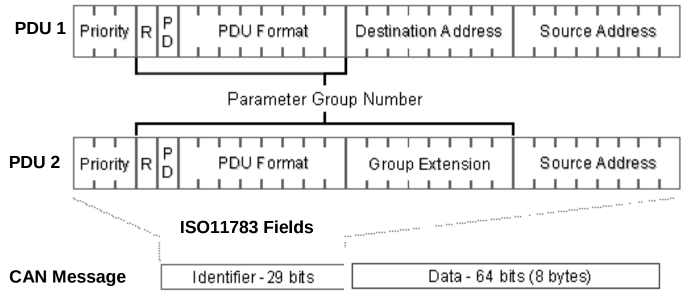


Figure 4. Identifier Structure and PDU Formation on ISO11783

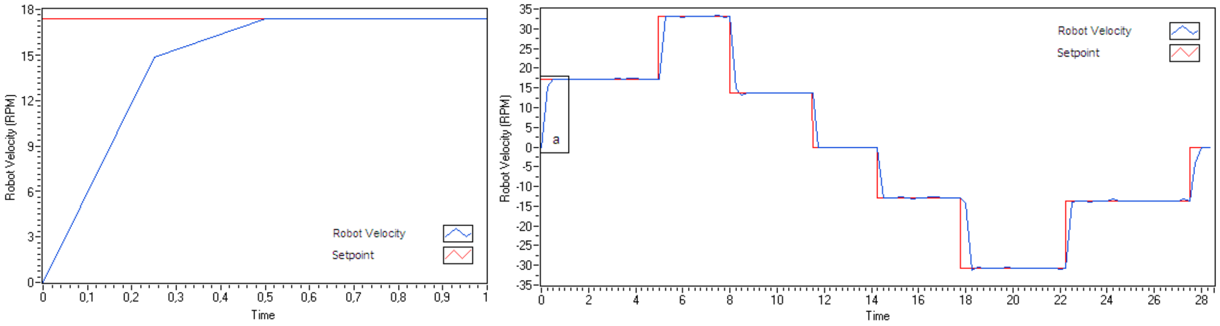
With the information about the CAN message fields, the message set for the ISOBUS network of the mobile robot was defined as shown in Table 1. All messages in the robot have the Priority field equal to 7 (decimal) and the Reserved and Data Page fields equal to O. The PDU Format was configured to 255 (value for proprietary use and open to users). The decimal value of the field is equivalent to its correspondent binary value (for example a value of 255 is equivalent to 11111111).The use of the fields in the identifier of the CAN message provide a lot of information that ease the distributed control of the robot. Each device in the robot has your own source address and each message has your own group extension. The value of the group extension defines the kind of information that the message carries (for example all messages with group extension equal to 10 contains information for control of the robot).

Table 1. Description of the CAN message set defined for the ISOBUS Network of the Mobile Robot (PGN – Parameter Group Number, PF – PDU Format, GE – Group Extension, SA – Source Address and DL – Data length of the message)

ECU	Information of the Message	PGN (HEX)	PF	GE	SA	DL
All	Address claim – ECU initialization	EE00	238	DA	254	3
Industrial PC	Propulsion control	FF0B	255	11	128	4
Right Side Box	Status message	FF0A	255	10	129	2
	Feedback of motors velocity and batteries voltage	FF0C	255	12	129	8
	Feedback of controllers temperature and motors current	FF0D	255	13	129	2
Left Side Box	Status message	FF0A	255	10	130	1
	Feedback of motors velocity and batteries voltage	FF0C	255	12	130	2
	Feedback of controllers temperature and motors current	FF0D	255	13	130	2
DGPS	GGA information: latitude, longitude, GPS quality, nº of satellites and HDOP	FF14	255	20	133	8
		FF14	255	20	133	8
Crop Circle	Information of sample number, R(IR) and R(VIS) data	FF15	255	21	134	8
Digital Compass	Angular orientation 0 to 360°	FF17	255	23	136	4
Ultrasonic Sensors	Information of culture height and distance of objects to the robot	FF18	255	24	137	8

3.2 Robot Operation Evaluation

With the teleoperated architecture implemented in the mobile robot and the controllers designed to the CAN network, the mobile robot operation could be evaluated. We performed field tests using the mobile robot to evaluate the architecture (response time of user commands and quality of motors control). In experiments, the user controls (teleoperates) the mobile robot navigation and the feedback information is analyzed to check the operability and accuracy of the robot movement. As cited earlier, the first operation tests are done with differential steering system for the mobile robot. The architecture time delay (response time of user commands transmission and feedback information for supervision) is also evaluated to verify its possible influence on the robot operation and supervision. Figure 5 presents the graphic of the step responses of the tractions motors of the robot for speed control. According to the propulsion design for the mobile robot, one rpm is equal to 0,035 m/s and its maximum velocity achieved is equal to 1,5 m/s.



(a) (b)

Figure 5. Test for Mobile Robot Speed Control: (a) Detail of the Step Response showed in the Rectangle *a* in Graphic (b) (red is the setpoint required and blue is the robot velocity), (b) Step Responses of the Traction Motors

The Figure 5 shows the accuracy of the traction motors response related to the setpoint required (negative values represent a robot velocity in a contrary direction). No steady state error can be found and the motors velocity increased like a ramp indicating the correct design of the PID controllers for mobile robot traction. All the four traction motor present the same response because the CAN network allow the transmission of messages in a diffusion mode. The industrial computer of the robot needs to transmit just one message in the CAN network and all ECU can receive this message and control the motors at the same time. This strategy do that the distributed control system do not present time delay or lack of synchronism in control commands reception.

The agricultural robot developed has an approximately weight of 500kg and a four wheel system. The distance between two wheels on each side is 2m. Tests are done with the mobile robot using the differential steering system. Because of the robot configuration, the differential steering system causes a great effort in the mechanical coupling between the wheels and the robot structure. At lower velocities (less than 0,5m/s) the mechanical structure support the effort and the robot can operate normally. However higher velocities may warp this mechanical coupling damaging the mobile robot movimentation. These results support the conclusion that the differential steering system cannot be used for normal operation (0,5 to 1m/s) of the agricultural robot developed and the latter requires a wheel steering system.

According to the feedback information obtained with the mobile robot traction test, the highest current used by the traction motors was 30A in maximum speed. In normal operation, between 0,5 to 1 m/s, the measured current was up to 18A. With theses values we can estimate operation autonomy for the robot of 4 hours with the batteries (70Ah traction batteries) currently used. The temperature of the propulsion controllers was also measured to verify possible problems. In the tests done, the temperature does not exceeded 50°C that is less than the maximum value (80°C) acceptable for the propulsion controllers.

The CAN bus load was measured in the robot operation and was less than 10%. This value is low and shows that the CAN-based distributed control of the mobile robot has capabilities to future expansions or new devices connections and increase in the data load and message traffic. The architecture time delay was evaluated by measuring the response time of user commands since beginning of the command transmission by the teleoperation station until the distributed control over the CAN network. The values measured do not exceed 100ms what indicates that the architecture time delay does not affect the robot operation and supervision and is adequate for teleoperation of the agricultural mobile robot developed.

Finally the results of the tests showed that the agricultural mobile robot could be teleoperated. Even though it is desirable to improve the mobile robot control (adding the guidance capabilities), the present level of accuracy and the architecture time delay is sufficient for teleoperation and remote sensing, and the results indicate that the developed architecture and the distributed control are useful for agricultural mobile robot operations.

Future work will be done to finish the integration of the guidance controllers in the CAN network of the robot and test the robot operation with the fully designed architecture. An improvement of the architecture developed to provide autonomous navigation capabilities to the mobile robot is also in the future tasks planned.

4. CONCLUSIONS

This paper presented the development of fieldbus architecture for teleoperation and distributed control of an agricultural mobile robot. The application of the ISO11783 standard based on CAN protocol provided an efficient platform to develop the distributed control system of the robot. Individual control nodes or electronic control units (ECUs) reduced the computational load of the task computer by implementing feedback control logic at the ECUs and ease the data communication between the devices of the robot. The CAN network allowed the transmission of messages in a diffusion mode doing that the distributed control system do not presented time delay or lack of synchronism in control commands reception (for example between the four controllers of the propulsion motors). The development of the ISO11783 library of high-level functions (initialization, management and communication) for microcontrollers is also an important contribution of this paper.

Tests were performed using the mobile robot to evaluate the fieldbus architecture develop in terms of the teleoperation system and the distributed control over the ISO11783 network. The values measured for the response time of user commands do not exceed 100ms what indicates that the architecture time delay does not affect the operability and supervision of the robot and is sufficient for teleoperation of the agricultural mobile robot developed. The PID controllers used to control the propulsion motors were designed to achieve a suitable and precise operation for the mobile robot navigation.

The results of the tests demonstrated that the developed fieldbus architecture can be applied for teleoperation and distributed control of agricultural mobile robots meeting the requirements for an accurate robot movement and an acceptable response time for control commands and supervision. However the tests done allow conclude that the differential steering system is not viable to be used with mobile robot developed (with four wheel system and 500kg of weight) with velocities higher than 0,5m/s and the robot requires a wheel steering system. Higher velocities may warp the mechanical coupling of between the wheel and the robot structure damaging the mobile robot movimentation.

It is expected that the results of this paper can contribute with research groups about agricultural mobile robots, CAN-based and ISO11783 distributed control technologies providing knowledge and enabling these implementation.

4. ACKNOWLEDGEMENTS

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