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Implementation and Evaluation of a CAN-Based Distributed Control System for Variable Rate Technology in Agricultural Machinery

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Abstract. *Precision Agriculture (PA) is management strategy for the agricultural production and involves multidisciplinary practices. The practices which use embedded electronic and remote sensing in agricultural machinery has demanded researches of sensors and communication networks for data acquisition and control in the farm field. The Distributed Control System (DCS) is the suitable solution for decentralization of the data acquisition system and the Controller Area Network (CAN) is the major trend among the embedded communications protocols. This work presents the implementation and evaluation of the CAN-Based DCS for the Variable Rate Technology (VRT) system. The VRT system is composed by a tractor-implement that applies a desired rate of inputs according to the georeferenced prescription map of the farm field to support PA. The distributed system consists in five devices, or Electronic Control Units (ECUs), responsible to the control for the VRT application. Four ECUs are located in the tractor: ECU0, ECU1, ECU2 and ECU3. The ECU0 is responsible to the Differential Global Positioning System (DGPS) positioning and dispose the coordinates in the CAN network. The ECU1 is responsible to manage the prescription map and to control the implement by CAN network. The ECU2 is responsible monitor the application analyzing the CAN network. The ECU3 dispose tractor velocity of a radar sensor in the CAN network. The fifth device (ECU4) is located in the implement, which is responsible to interpret the commands from the tractors ECUs by CAN network and integrate the mechanical-hidraulical device to do the variable application. The evaluation of the performance the P controller by CAN network was done and analyzed the control error according to the necessity of agricultural application. The implementation of CAN-Based DCS for the agricultural area reached considerable control errors, however it's suitable for the agricultural productions. The future work is changing the P controller to PI controller to reduce the control error.*

Keywords*: Distributed Control Systems; CAN networks; Electronic Control Unit (ECU); Variable Rate Technology (VRT); Prescription Map*

1. INTRODUCTION

The contemporary agricultural mechanization adopted the concepts and skills of automation and computer science by providing support for more precise management of agricultural production. This type of management is called Precision Agriculture (PA). PA is management strategy for the agricultural production and involves multidisciplinary practices (Gozdowsk and Samborski, 2007). The practices which use embedded electronic and remote sensing in agricultural machinery has demanded researches of sensors and communication networks for data acquisition and control in the farm field (Wei *et al.*, 2005). The Distributed Control System (DCS) is the suitable solution for decentralization of the data acquisition system and the Controller Area Network (CAN) is the major trend among the embedded communications protocols (Pereira, 2008a). The several works confirmed the usage of CAN protocol for agricultural machinery, as following citation: Du *et al.* (2008); Godoy (2007); Guimarães (2003); Landi (2004); Miettinen *et al.* (2006); Oksanen *et al.* (2005a); Oksanen *et al.* (2005b); Pereira (2008); Pereira *et al.* (2008); Sakai (2008); Sousa (2007); Suvinen and Saarilahti (2006).

The soils correctives are fundamental inputs in agricultural exploration. The Brazilian soil has high acidity and this condition is unfavorable to plant. So, the correct input application assumes an important signification, in terns of soil fertility, yield and economic factors. The efficiency of the inputs in the agricultural productive process is dependent of its quality and application way at soil. Errors in one of the stages above affect directly the agricultural yield. This work presents the implementation and evaluation of the CAN-Based DCS for the Variable Rate Technology (VRT) system a soil corrective in agricultural machinery. In the next section will expose the PA review, the agricultural machinery and the CAN messages. In the section 3 will talk about results and discussion. And the section 4 will say the results of this work.

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2. MATERIAL AND METHODS

The requirements for the implantation of this work were divided in the review of Precision Agriculture phases and technologies, the development of the CAN-Based Distributed Control System in agricultural machinery and a creation of a set of CAN messages for the evaluation the agricultural implement to effectuate VRT application.

2.1 Review of the Precision Agriculture

The basic principle of Precision Agriculture (PA) is handling the variability of soil and crops in space and time. This variability are of the soil, the climate, the diversity of cultures, the performance of agricultural machinery and natural or synthetic inputs used in agricultural production. Based on these principles are given some definitions of the term PA:

• "A management strategy that uses Information Technology (IT) to collect data from multiple sources to support decision making system of the agricultural production." (National Research Council: Board on Agriculture, 1997);

• "A set of techniques that allows the management of localized cultures." (Balastreire *et al.*, 1998);

• "Precision agriculture is the application of principles and technologies to manage the spatial and temporal variability, associated with all aspects of agricultural production to increase agricultural productivity and environmental quality." (Pierce and Nowak, 1999);

• "A set of techniques and crop management actions taking into account the variability of soil parameters and the behavior of the crop in the plot." (Menegatti and Molin, 2004);

• "PA is defined as a holistic strategy and protective of the environment in which agricultural producers may change the use of materials and methods of cultivation to match the variation of soil and cultural conditions across the country. There are still other definitions and all these suggest that there are at least three critical elements to the success of PA: information, technology and management." (Srinivasan, 2006).

A PA system should have the ability to relate the measures of the field and interpretation of spatial and temporal variability, generating information for the management of variability by the application of inputs. These applications should be located and made by machines and devices for the correct application of different inputs in a specific location. The PA system should be able to register the data of the applications for review by a specialist team, and after examination, should be generated action plans for future management of the variability. The following process "field data acquisition" → "data analysis" → "planning of the management field" → "management of the field" of the PA is cyclical, and this feature is called cycle of PA or PA phases, and Figure 1 show according to Molin (2003).

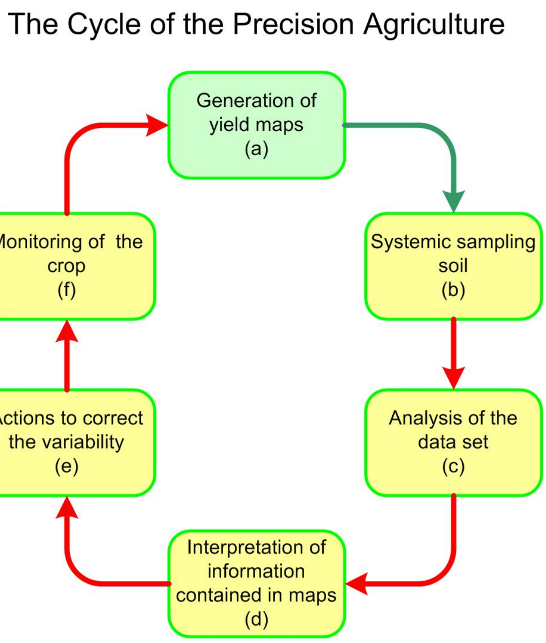

Figure 1: PA phases. Source: Molin (2003).

Those phases enabling a large number of technologies, for example, the Global Positioning System (GPS) guidance, field mapping by Geographic Information System (GIS), satellite or aerial imagery, soil electrical conductivity mapping, remote sensing, soil sampling techniques, Variable Rate Technology (VRT) and others. The adoption of PA along of ten years ago is demonstrated in the Crop Life Report: 2008 Precision Agricultures Services from Center for Food and Agricultural Business of Department of Agricultural Economics of Purdue University (Whipker and Akridge, 2008). The Figure 2 (a) shows the graph of the usage of PA technologies between 2003 to 2008 years, Figure 2 (b)

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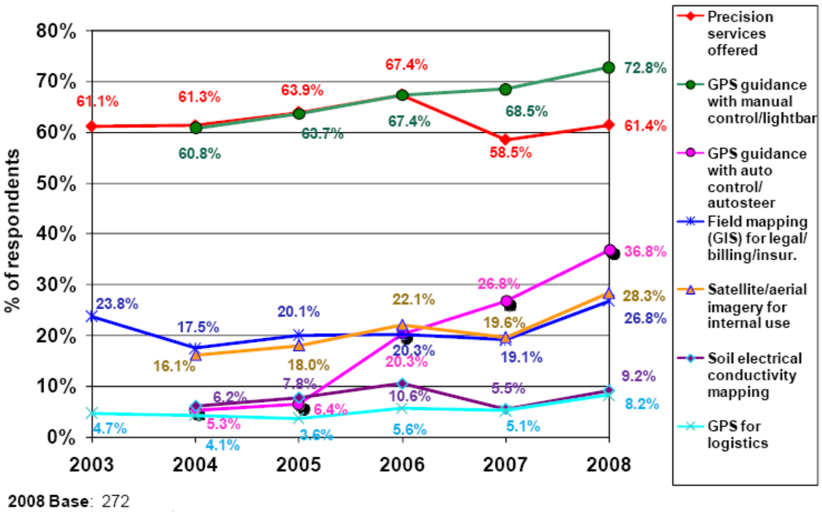
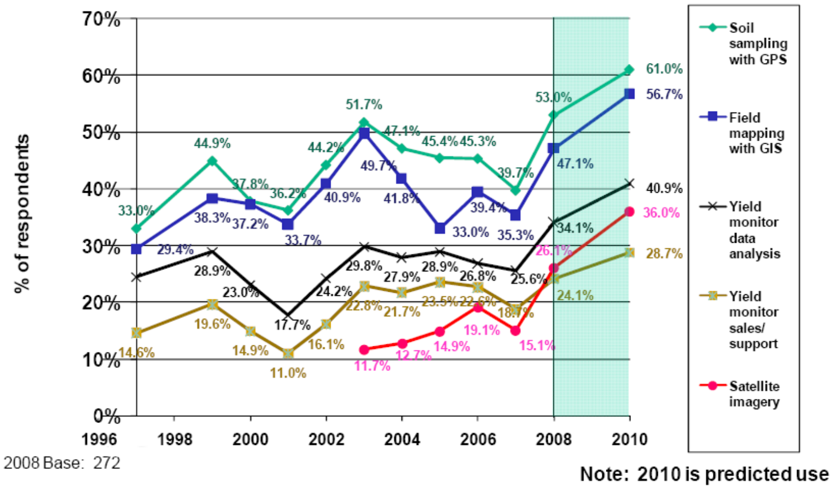
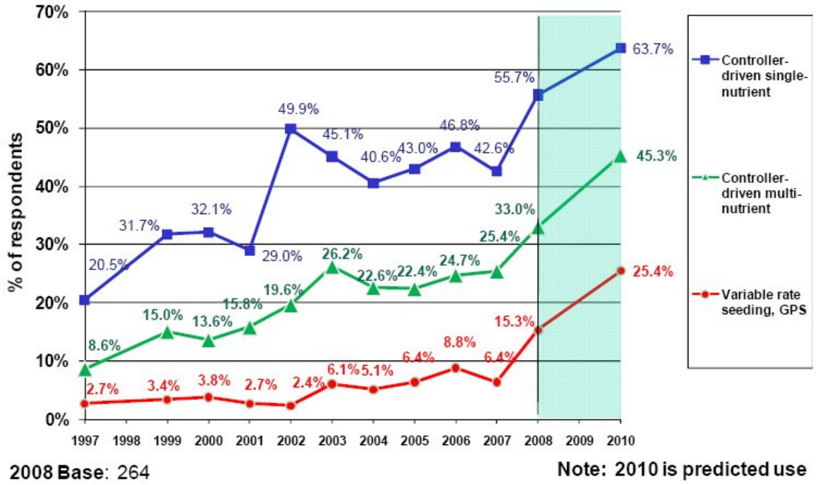
show the graphs of the usage of PA services between 1996 to 2008 years with predicted use for 2010 year, and Figure 2 (c) show the growth of variable rate application using VRT between 1997 to 2008 years with predicted use for 2010 year.



(a)



(b)



(c)

Figure 2. (a)Use of enabling technologies of PA over time (b)Use of PA services over time. Source: Whipker and Akridge (2008).

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According to the Figure 2 (a), Figure 2 (b) and Figure 2 (c), it notices since 2007 year the use of technologies and services increased linearly, showing the acceptance of PA. The relationship between the cycle of PA (Figure 1) with the technologies and services is shown in Table 1.

Table 1. Relationship between the Figure 1 with the Figure 2.

Technologies and Services	Phases of PA
GPS guidance with manual control	(a)(b) (e)(f)
GPS guidance with auto control	(a)(b) (e)(f)
Field mapping (GIS)	(c)(d)
Satellite/ aerial imagery	(b)(c)(d) (f)
Soil electrical conductivity mapping	(b)(c)(d)
Soil sampling with GPS	(b)(c)(d)
Field mapping with GPS	(a)(b)(c)(d) (f)
Yield monitor	(a) (c)(d) (f)
Data analysis	(c)(d) (f)
GPS for logistics	(a)(b) (e)(f)
Variable rate applications (VRT)	(a)(b) (e)(f)

Based on Table 1, in practical way, we can associate those technologies and services with the agricultural applications of the PA.

2.2 Agricultural Machinery for VRT application and The CAN-Based Distributed Control System

Most tractors are manufactured in Brazil haven't CAN bus. But there is a demand for tractors with CAN bus due to the recent growth of the CAN protocol implementation in agricultural machinery. It was found that the company Valtra (Valtra, 2009) had a prototype tractor BM125i (Figure 3) with a CAN bus.

The principal types of soil correctives and fertilizers machinery applicators are defined by its functionality. There are applicators which work with gravity and with centrifuge force. The gravity machinery has the inputs distribution continuous fillets. The gravity machinery presents major potential of uniform distribution transversal and longitudinal than the centrifuge forces machinery. We adopted the gravity machinery implement DMP 7500 (Figure 3) from Baldan (Baldan, 2009) used in Pereira *et al.* (2007) that which capable to apply the specific rate at specific location.

The distributed system consists in five devices, or Electronic Control Units (ECUs), responsible to the control and the management for the VRT application, shows in the Figure 3.

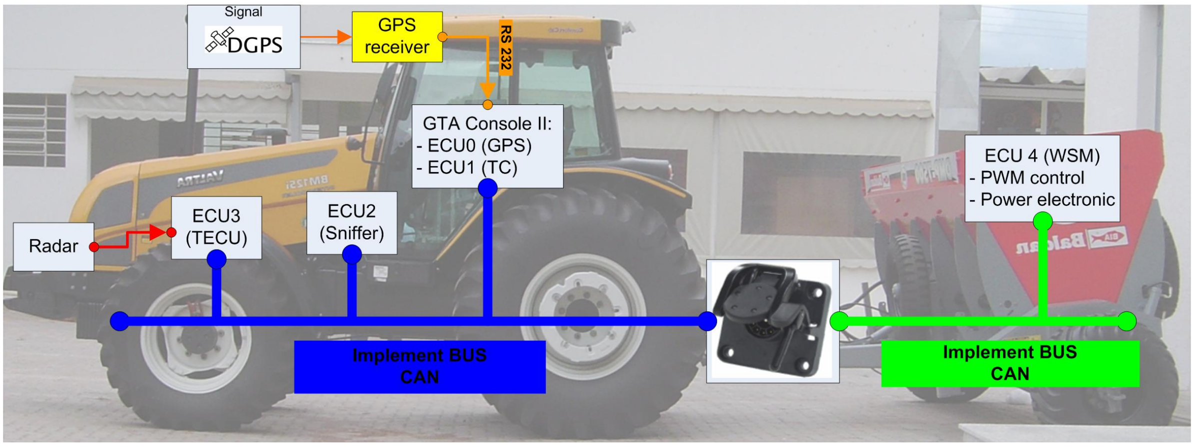

Figure 3. Schematics of the CAN-Based Distributed Control System developed for agricultural machinery

The ECU is the hardware responsible for the control, data acquisition and communication between the devices in the CAN network. Four ECUs are located in the tractor: ECU0, ECU1, ECU2 and ECU3. The GTA Console II, from AGCO Corporation (Agco, 2009), is a commercial terminal with Human-Machine Interface (HMI) and constituted of ECU0 and ECU1. The ECU0 (GPS) is responsible to the Differential Global Positioning System (DGPS) positioning and dispose the coordinates in the CAN network. The ECU1 (TC – Task Controller) is responsible to manage the prescription map, to store the application data and to control the implement by sending the desired rates of inputs via CAN network. The ECU2 (Sniffer) is PCMCIA CAN-bus sniffer from Vector (Vector, 2009) installed in a laptop computer, witch is responsible to monitor and analyzing the application by the data messages exchange via CAN network. The ECU3 (TECU – Tractor ECU) disposes tractor velocity of a radar sensor in the CAN network. The fifth device, ECU4 (WSM – Working Set Master), is located in the implement and was developed based in Pereira *et al.* (2007) for this work. The ECU4 has a microcontroller PIC18f258 of Microchip (Microchip, 2009); a CAN

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Transreceptor to make the interface among the microcontroller and CAN bus; a RS232 Transreceptor. ECU4 is responsible to interpret the commands from the tractor ECUs via CAN network and integrate the mechanical-hidraulical device to do the variable application according to the prescription map.

2.3 The set of CAN messages

Based on ISO 11783 standard (ISO 11783-1, 2007), rules are defined for the startup process of the ECU in a CAN network, , using the definition of the Source Address (SA) messages, the exchange of information between the ECU already initialized and operating normally with the ECU in the boot process. The data link layer uses the version 2.0B Extended of the CAN protocol (Bosch, 2009) and the exchange of messages occurs at 250 kbit/s bus speed. The data field of the message is from zero to eight bytes (64 bits) and the field identifier (Identifier) 29 bits that has characterized the message frame as you can see in Figure 4.

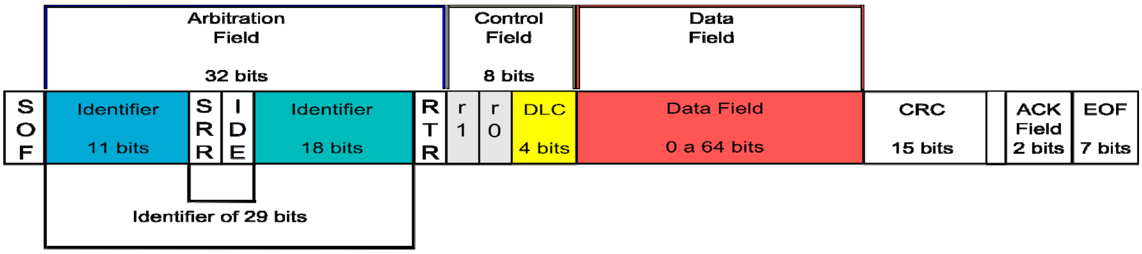

Figure 4. Frame of CAN 2.0B (CAN Extended). Source: adapted from ISO 11783-3 (1998).

The field identifier allows messages to be seen as information with different priorities independent of the ECU. Besides, the CAN protocol are defined ways to use bits of the field identifier and field data, which form a CAN message, as illustrated in Figure 4. It defined two patterns of the bits use called Protocol Data Units (PDU), which are PDU1 and PDU2. These PDUs are structures that allow for different message types to address a message. The PDU1 structure allows an ECU send a message directly to another ECU. The structure PDU2 allows identifying the data type of the message, but does not address the message to a specific ECU, providing for the connected ECUs to filter and to evaluate the content of the message by its identifier and decide whether or not receiving this message. Figure 5 shows the two types of PDUs for the message exchange.

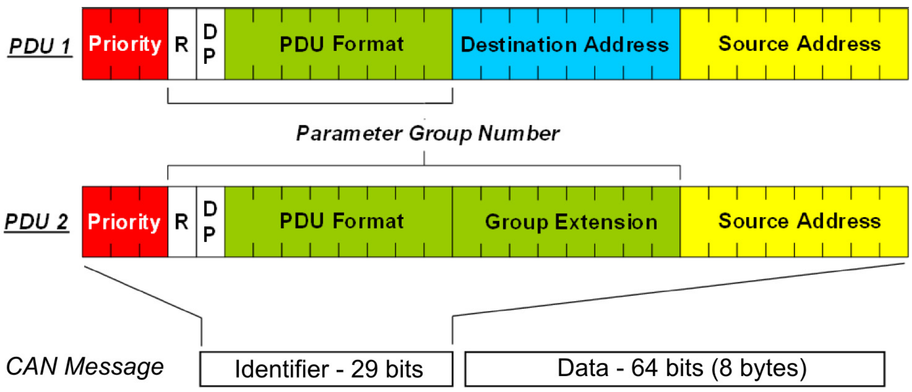

Figure 5. PDUs types of the identifier. Source: adapted from ISO 11783-3 (1998).

There are 256 possibilities (0 to 255 - 8 bits) of the SA, verified by the size of the fields Source Address and Destination Address (DA) in Figure 5 of the two possible structures for the identifier (PDU1 and PDU2). The 255 address is the global destination address and the address 254 is a null address used for administration of the network. The field PDU Format (PF) of the identifier allows for the connected ECU to identify the type of PDU (PDU1 or PDU2) which is being used to the message communication from other ECU. If the PF field (8 bits) has decimal value equal to or greater than 240 is PDU2, if not this will be PDU1. The other function of the PF field associated with the Reserved (R) and the Data Page (DP) fields is the formation of the Parameter Group Number (PGN). When the message is PDU1 the PGN has 10 bits, in another case when is PDU2 the PGN has 18 bits and is added the field Group Extension (GE). The fields DA and GE are also referred to as PDU Specific (PS). The message data could be classifies in data measured, status or command. The sets of parameters that have similar characteristics are grouped together to compose a message on a specific type, such as messages with the engine or navigate parameters. This group of parameters is called Parameter Group (PG) and is defined message format for each PG. The PGN joint with the PG,

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implements a way to indicate the contents of a data message for the 8672 possibilities of PG. Table 2 shows a set of the initialization and process data messages used among the ECU1 and ECU4, the message of speed and the message of de GPS coordinates.

Table 2. Process messages. Based on ISO 11783-10 (2007).

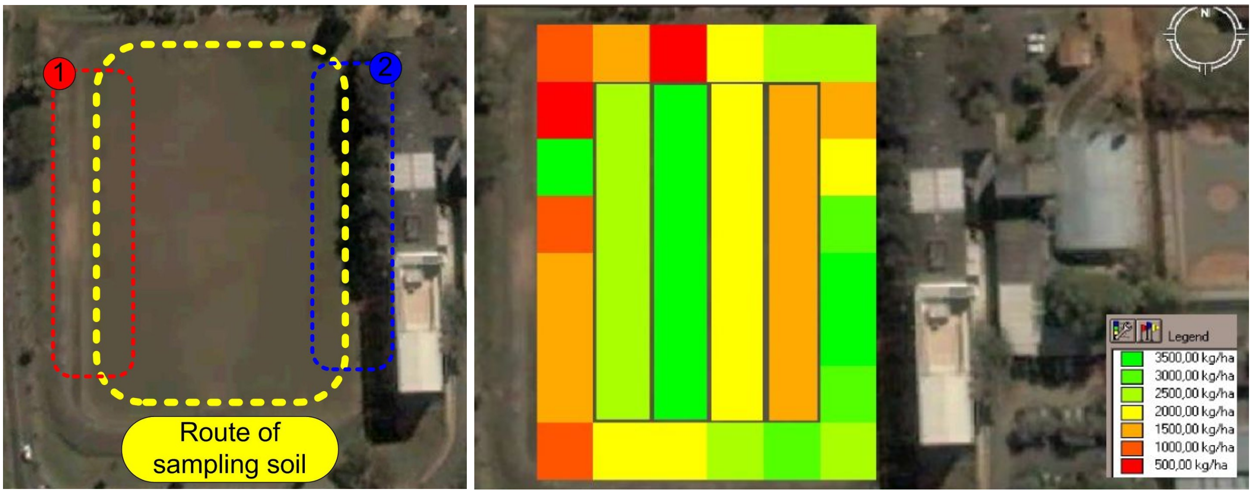
PGN	Control Byte Data field - BYTE 00	Message	Data field BYTES 01 – 07
DP=0 PDUF = 203 (0xCB) PDUS = DA Priority = 3 PGN = 51968 (0x00CB00)	0x0E	*Task-controller status message*	04 to 07 indicate TC status
	0x0F	*Working-set task message*	04 to 07 indicate WSM status
	0x0D	*Negative acknowledge (NACK) message*	04 indicate the error type. If is 0x01 means there isn't activated DDOP
	0x00	*Request version message*	All reserved (0xFF)
	0x10	*Version message*	02 indicate the version
	0x01	*Request structure label message*	All reserved (0xFF)
	0x11	*Structure label message*	01 to 07 are the 7 characters of the DDOP structure label
	0x21	*Request localization label message*	All reserved (0xFF)
	0x31	*Localization label message*	01 to 06 are the 6 characters of the DDOP localization label
	0x41	*Request object-pool transfer message*	01 to 04 indicate the size of the transferred file
	0x51	*Request object-pool transfer response message*	01 indicate if the TC has enough store file space
	0x61	*Object-pool transfer message*	01 to n, the number n varies depending on the size of DDOP
	0x71	*Object-pool transfer response message*	01 indicates if the file transfer was successful. 02 to 05 indicate the size of DDOP
	0x81	*Object-pool activate message*	01 to 07 reserved (0xFF)
	0x91	*Object-pool activate response message*	01 to 06 indicate if there is an error in DDOP
	0x13	*PDValue*	02 to 03 indicate the DDI = 6. 04 to 07 indicate the variable value of the process (desired rate)
			BYTES 00 – 07
DP = 0 PDUF = 254 (0xFE) PDUS = 73 Priority = 3 PGN = 65097 (0x00FE49)	*[1]	*Ground-Based Speed And Distance*	00 to 01 indicate the ground based speed
DP = 1 Priority = 3 PGN = 129025 (0x1F801)	*	*GNSS Position Rapid Update*	00 to 03 indicate the latitude and the 04 to 07 indicate the longitude.

From the group PGN = 0x00CB00 (Table 2), the messages with control bytes 0x0E and 0x0F indicates the status of ECU1 and ECU4 respectively. The messages with control bytes 0x0D to 0x91 are for the initialization and configuration among ECU1 and ECU4. And the last one of this PGN group, with control byte 0x13, indicates the process value variable, in this work means the desired rate according to the prescription map. The message with PGN = 0x1F801 is for the GPS coordinates and the PGN = 0x00FE49 is for the tractor speed based on the ground.

3. RESULTS AND DISCUSSION

An experiment was done to check the results of the CAN-Based Distributed Control System. In this experiment, the ECUs communication test was done with a tractor and the VRT implement for application of soil corrective, both with a CAN bus network, at Laboratory of Simulation and Control (Simulation and Control, 2009) of the Department of Mechanical Engineering of School of Engineering of São Carlos – University of São Paulo (EESC-USP). But, before to do the test, a prescription map was generated based on Cycle of PA (Figure 1) using the PA technologies (Figure 2). The map generation started in phase (b) using an active chlorophyll crop sensor with GPS receptor to measure the spatial variability geographically. Next were the phases (c) and (d) using the GIS software GTA suite software (Agco, 2009) for analysis and build the prescription map archive and satellite imagery from Google Earth (Google Earth, 2009) to notice the visual variability. The Figure 6 (a) presents the route of the sampling soil with the region 2 is more shaded than the region 1, i.e., the region 1 receives more sunlight than the region 2. And the Figure 6 (b) shows the georeferenced prescription map of soccer field of the EESC-USP of the interpreted variability with respective legend of the desired rates to treat the soil on phase (e). The phase (e) consist the VRT application according to prescription map.

[1] Hasn't control byte.



(a) (b)

Figure 6. The EESC-USP soccer field of the prescription map. Source: Google Earth (2009) and GTA Suite Software (2009).

After the generation, it setup to go to the phase (e) using the Agricultural Machinery for VRT application and The CAN-Based Distributed Control System. All the communication and command process is done by exchange messages through CAN bus network and the ECU2 was used to monitor and collect the messages exchange during the process. The prescription map was inserted on ECU1 and the initialization among ECU1 and ECU4 was started, as we can see the logged messages exchanged in the Figure 7.

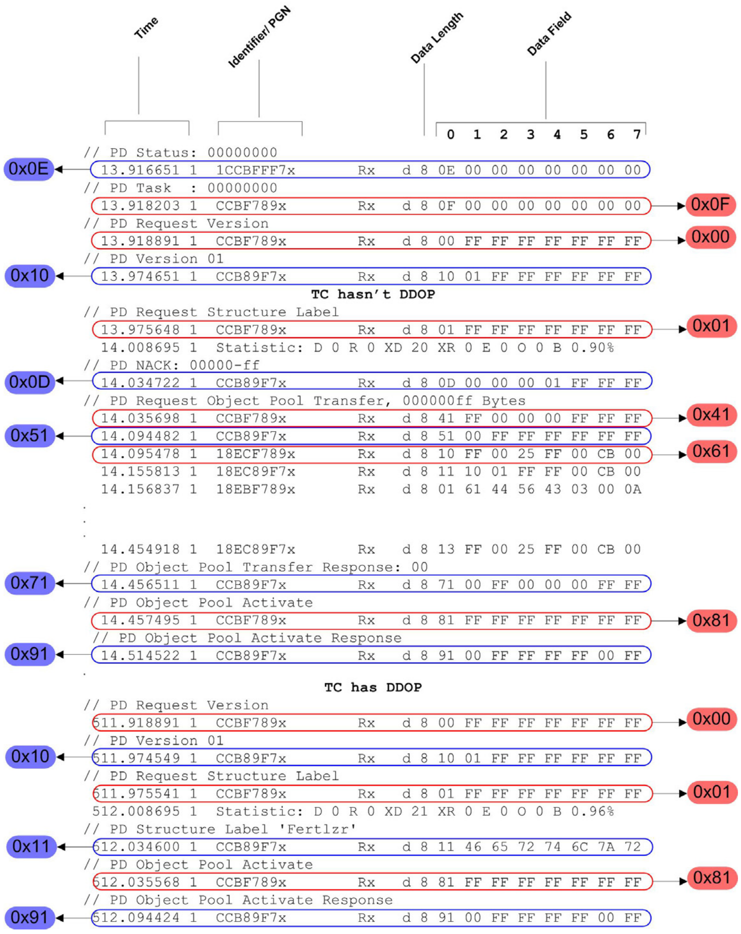


Figure 7. The CAN messages log of the initialization process among ECU1 and ECU4.

Using the Table 2, messages of Figure 7 was interpreted. A condition for the initialization start is the ECU1 and ECU4 must send status message, and the condition was satisfied with the messages 0x0E of the ECU1 and 0x0F of the ECU4. The initialization and configuration began with ECU4 message 0x00 and finished with ECU1 message 0x91. After that, when the tractor and implement transit over the prescription map area the VRT application commence if the ECU1 and the ECU4 still send the *Status* message, as we can see in the Figure 8 (a.0) and the status change to 01 (Figure 8 (a.1)).

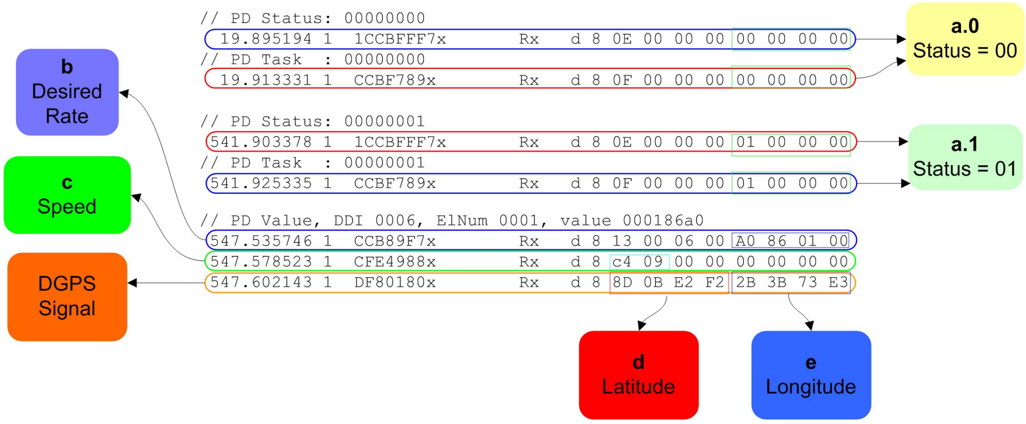


Figure 8. The CAN messages log of the VRT application using ECU0, ECU1, ECU3 and ECU4.

The Status = 01 means the VRT application is activated. The tractor velocity is measured by the radar sensor at ECU3 and this information is transmitted on the implement bus by message *Speed* (Figure 8 (c)) to the ECU4 that controls the hydraulic motor. The hydraulic motor is responsible to control the rotation of the endless spiral that changes the input application. The coordinates of the GPS was send by ECU0 message *DGPS Signal* (Figure 8 (d) *Latitude* and (e) *Longitude*) and are used to by ECU1 to check witch application rates is necessary to send to the ECU4. And finally the desired rate was send by ECU1 message *Desired Rate* (Figure 8 (b)). In this message sample, the desired rate was send is 1000 kg/ ha (or in the data field 0xA08601). With the desired rate, the ECU4 does a proportional controller (P controller) of the rotation of the VRT system shaft by power electronic. To effectuate the P controller, the ECU4 read the tractor velocity and desired rate to calculate the desired rotation. The desired rotation is the necessary rotation of the VRT shaft to apply the desired rate required. The VRT system developed presented a maximum error of 20%. This error could be explained due to the delays in message transmissions and in the mechanical-hydraulic actuators. The obtained error value was not critical for the type of application (soil corrective) which the system was developed.

4. CONCLUSION

In this work was showed the implementation of a CAN-Based Distributed Control System for Variable Rate Technology in Agricultural Machinery using a prescription map in automatic way. The evaluation done is about the validation of the communication and control by CAN bus network analyzing the collected messages. Was demonstrated how the apply PA in practical way using the enabling technologies and concepts and the acceptance of PA in last years. The implement presented acceptable results (application rate error) for the utilization in soil corrective application systems.

This work contributed with research groups about the CAN bus standard and making possible its development and implementation for the national industry in agreement to the news worldwide tendencies agricultural machinery area. The future works include changing the P controller to PI controller to improve the results of the VRT system.

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