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Evaluation of the Implementation of ISO 11783 for 250 kbps Transmission Rate of Tractor Electronic Control Unit

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Abstract

Purpose: Accurate monitoring of information from various agricultural vehicles is one of the most important factors for appropriate management strategy of field operations. While there has been a number of study and design on applications of sensors and actuators for data acquisition and control system in tractor, incompatibility between various customized hardware and software has become a major obstacle to the universal deployment in real field operation. International standard for implementation of electronic control unit (ECU) in agricultural vehicles has becoming a mandatory requirement for inter-operation compatibility in the international trade of agricultural vehicle industries. The ISO 11783 standard is basically based upon well known communication technology designated using the controller area network (CAN) bus. While CAN bus could provide 1.0 Mbps of communication speed, the standard only recommended 250 kbps. **Methods:** This study presents the implementation and evaluation of ISO 11783 for tractor electronic control units (TECU)with a higher transmission rate from multiple ECU than 250 kbps. Throughput and loss rate of the developed prototype were calculated across manipulated bus load for laboratory experimental tests, and the maximum requirement of transmission rate by ISO 11873 was satisfied with lower than 60% of bus load. **Results:** Field tests with a TECU implemented to process messages from global positioning system (GPS) receiver resulted that the root mean square error of position information was lower than 4 m with 0.5 m/s as a travelling speed. **Conclusions:** Results of this study represent the utilization of the international standard ISO 11783 to providepractical developments in terms with the inter-operability of TECU.

Keywords: Agricultural tractor, Communication, Controller area network, ISO 11783, Tractor electronic control unit

Introduction

Accurate monitoring of information from agricultural vehicles and machines is one of the most important factors for efficient field operations. For application with higher precision, the more accurate monitoring system would be strongly recommended. Besides, the probability of potential latency time or error in the communication between devices could lead us to failures in a designed performance. Thus, a basic communication method and its implementation should be proved to be suitable to satisfy the requirement for real field operations.

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The international standard ISO 11783, which is commonly referred to as ISOBUS, describes CAN (Controller Area Network) based communication (Bosch, 2008) of open networks for mobile use in agricultural field, and the protocol is harmonized in accordance with SAE J1939. A typical CAN network is composed of ECUs sending and receiving their messages on a common bus. The feature of CAN communication protocol is to encode a 8 bytes data block, which can meet electric bus control commands, such as working status and test data requirement. ISO 11783 specifies a serial data network for control and communications of forestry or agricultural tractors, mounted, semi-mounted, towed or self-propelled implements, and also specifies data communications between tractor electronic control units (TECU), virtual terminals (VT), and connected implement computers. ISO 11783-2 (2002) describes 250 kbps, twisted, non-shielded, quad-cable physical layer.

ISO 11783 has become an indispensable part of data communication in the agricultural vehicles and the agricultural machinery products. During the development of this standard, Benneweis (2005) addressed the fundamental requirements of each part to complete the design of an agriculture and forestry compliant. Continuous outstanding functional innovations, markedly in the regions of safety, comfort and chassis functions, are expected for future development of agricultural vehicles. Additionally, industries are searching for methods to manage the increasing complexity of electronic control system in the agricultural vehicles and machines. For example, Ni et al. (2009) developed an agricultural air quality system for livestock and poultry environments using new on-site computer system. A computer and a commercial data acquisition device, USB-1608FS (NI, Austin, Texas, USA), were used to develop a customized measuring and control system. However, the customized system has not been widely applied to real fields due to the complexity of integration and economical benefits.

Many researchers have developed communication networks using CAN bus for data acquisition and control in agricultural fields. Darr et al. (2005) evaluated the potential of a CAN bus to be used as the communication network for a distributed control system on an autonomous agricultural vehicle. In their study, the proper implementation of task computer based on standard was emphasized for a control system with simultaneous and fast responses in agricultural vehicles. Oksanen et al. (2005) developed a positioning system for agricultural vehicles with a low-cost global positioning system (GPS) receiver. In this research, they noted that the compatibility between various electronic components designed for precision agriculture, autonomous travelling and light-bar navigation should be carefully considered for future potential applications. Pereira et al. (2007) presented the usability of a CAN-based distributed control system for a variable rate technology. Multiple ECUs including a pressure monitoring ECU, a linear displacement monitoring ECU and a post processing ECU with GPS receiver were developed to manage geographical information from DGPS and signals from hydraulic devices for a variable application, and ISO 11783 was applied for the communication between the ECUs. Steinberger et al. (2009) proposed a mobile farm system to collect a large amount of data in real time. They implemented an infrastructure for data management in information-driven plant production based upon ISO 11783. Collected data from the standard management system were suitable to be processed through an internet application. Suvinen and Saarilahti (2006) developed a CAN bus system consisting of 8-wheel forwarder's hydrostatic transmission and a GPS receiver to estimate total resistance force and wheel slip under different terrain conditions. They concluded that the measuring technique using the CAN bus was effective for terra mechanical research with real forestry conditions such as extremely rough terrain. Wei et al. (2005) emphasized the importance of efficient system integration in agricultural machines and processes. In their study, the use of IEEE 1451 standard to facilitate plug-and-play for sensors and actuators were presented by designing smart transducers, and compatibility between ISO 11783 and IEEE 1451 was analyzed. An example of a weed sensing system was developed using both two standards. Considering pros and cons with the use of standards, an accurate recognition of system requirements (e.g. resolution and frequency) should be carefully considered for the implementation of the standards.

The most important component in the implementation of ISO 11783 is a TECU that provides a gateway between a tractor bus and an implement bus. TECU is responsible for transmitting information from tractor to a communication network and corresponding commands to a tractor. ISO 11783 specifies three tractor classes depending on the available features of the tractor electronic control unit. Class 1 TECUs provide the implement bus only with basic tractor internal measurements, such as travelling speed, PTO status, and hitch information. Class 2 TECUs provide more advanced measurements, such as measurements the horizontal force of a rear hitch and flow rates of hydraulic valves. Class 3 TECUs are prepared to take commands from tractor's rear-hitch, PTO and auxiliary valve control.

Regarding the implementation of an ISO 11783 system for field operations, VT is an end interface component for users or farmers. Thus, this component should also be straightforwardly considered in the process of development. VT provides a common user interface to all valid functions on the standard bus containing a graphic display with a pre-defined set of graphical objects, a few soft keys with an icon on display, means to navigate on display for manipulation of the values and the action (ISO, 2004). The display shown in VT is stored in "object pool". The object pool is a representation of a working set, and consists of objects supported in the standard. The objects may be input numbers, output numbers, bar meters, needle meters, polygon graphics, or bitmap graphics. The objects have parameters like position, size, color and value.

Most studies about ISO 11783 have focused on implementation methods for TECU and VT. However, specific approaches of ISO 11783 implementation to TECU has not been sufficiently examined in the sector of the Asian agricultural industry including the Republic of Korea. Additionally, while CAN bus could provide a 1.0 Mbps of communication speed, the standard only recommended 250 kbps. In case with various potential instances caused by both technical improvement and growing complexity in tractor operation, the processing of a large amount of data transmission from multiple TECUs should be examined considering the limited communication speed less than 250 kbps that is a recommended communication speed by the specification.

The objective of this study was to evaluate a CAN bus based TECU system for 256 kbps data communication rate. A prototype of TECU system recommended by the ISO 11783 standard was developed using a 32-bit microprocessor. In order to ensure proper operation of the integrated communication system, functional tests under the laboratory and field conditions were performed.

Materials and Methods

Specifications of ISO 11783

ISO 11783 standard is a set of definitions, rules and procedures designed to allow connection and information exchange between control units of a tractor and an agricultural implement. ISO 11783 was established with the union of two other standards: LBS/DIN 9684 (Auernhammer and Frisch, 1993) and SAE J1939 (Auernhammer and Speckmannm, 2006), both standards based on the previous version of CAN protocol (Bosch, 2008). A typical CAN network is composed of several ECUs sending and receiving their messages on a common bus. CAN protocol allows simultaneous bus access from different nodes. Following the ISO 11783 standard, we designed the method for implementation of ISO 11783. Figure 1 shows the two parts of the implementation.

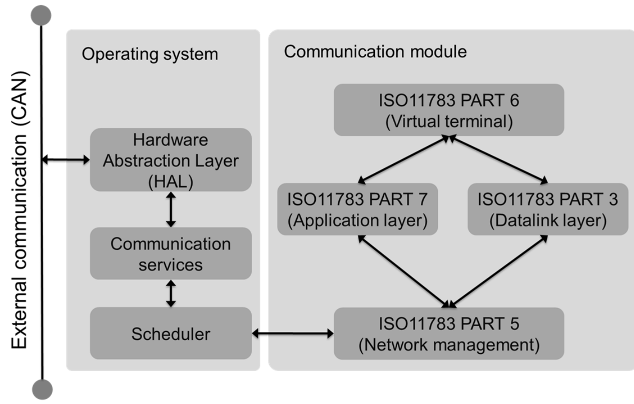


Figure 1. Schematic diagram explaining method of ISO 11783 implementation.

Part 9 of ISO 11783 (ISO, 2002) specifies a serial data network of control and communications for forestry or agricultural tractors and mounted, semi-mounted, towed or self-propelled implements. The purpose is to standardize the method and format of data transfer among sensors, actuators, control elements, information storage and display units, whether there are mounted on, or part of the tractor or implement. The tractor ECU is also the node that represents the tractor, or analogous functions, of self-propelled machines, such as the virtual terminal on the implement bus. Tractor class defines a minimum set of messages that a tractor ECU is able to provide on the implement bus to connected implements. Table 1 shows the set of information (ISO, 2002) required to implement the TECU. The information items bolded were selected in evaluation tests. We used the message structure (e.g., Table 2) of these items as parameters of TECU for communication with the main ECU (ISO, 2007). Each part of ISO 11783 was implemented into the developed TECU. Specifications of VT (ISO, 2004), message implementation (ISO, 2009), data exchange (ISO, 2007) were applied for component implementation.

Implementation of Main ECU, TECU and VT prototype

The processor used in this study is the 32-bit microprocessor (ARM Cortex^{TM}-M3, ARM, UK) for real-time applications. The microcontroller-embedded board of our system consists of an 1-layer PCB (printed circuit board). According to specifications provided, a test board (STM32F103ZE, STMicroelectronics, USA) incorporates a

Table 1. Summarized classifications of TECU interface recommended by ISO 11783-9 (Bold entries represent implemented TECU message)

Implementation level	Implementation target	Description of parameters
Class1	Power management	Key switch state
		Maximum time of tractor power
		Maintain power request
	Speed information	**Wheel-based implement speed**
		Ground-based implement speed
		Engine speed (Transmission rate = 100 ms)
	Hitch information	Rear hitch position
		Rear implement in-work indication
	PTO information	Rear PTO output shaft speed
		Rear PTO output shaft engagement
	Lighting	Left-turn signal lights
		Right-turn signal lights
		Marker light
		Left stop light
		Right stop light
		Implement rear work light
Class2	Basic	**Ground and wheel based distance and direction**
		Rear draft information
		Complete lighting message
		Auxiliary valve status
	Extended	**Time and date**
		Speed and distance (ground and wheel based)
		Additional hitch parameter : rear draft
		Full implement lighting message set
		Estimated/measured auxiliary valve status
Class3	Hitch information	Rear hitch position
	PTO information	Rear PTO output shaft speed set point Rest PTO output engagement
	Valve information	Auxiliary valve command

Table 2. One of message structure for transmitting TECU information recommended by ISO 11783-10

Issue	Description
Parameters	Ground-based machine speed
Resolution	0.001 m/s/bit, 0.256 m/s/bit
Range	0 ~ 64,255
Type	Measured sensor value
Identifier	1859
Unit	m/s

32-bit RISC (reduced instruction set computer) core operating at a 72 MHz frequency, high-speed embedded memories, and an extensive range of enhanced inputs and outputs. All devices offer three 12-bit ADCs, four general-purpose 16-bit timers plus two PWM timers, as well as standard and advanced communication interfaces: up to two I2Cs, three SPIs, one SDIO, five USARTs, an USB and a CAN. The CAN of the board is compliant with specifications 2.0A and 2.0B with bit rates up to 1 Mbps. It can receive and transmit standard frames with 11-bit identifiers as well as extended frames with 29-bit identifiers.

A task controller is another special ECU connected to the implement bus, and provides task management for the machines connected to the ISO 11783 network. Tasks can be pre-planned and loaded to the task controller executing them on the field by commanding other ECUs. A task may be, for instance, seeding different parts of a field with different seed varieties. To execute position-dependent tasks, a GPS receiver is connected to the implement bus.

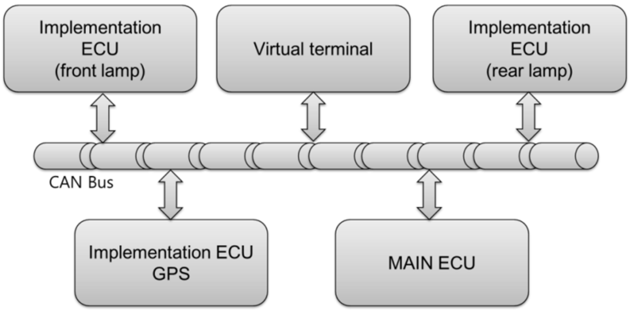


Figure 2. Schematic diagram of prototype configuration.

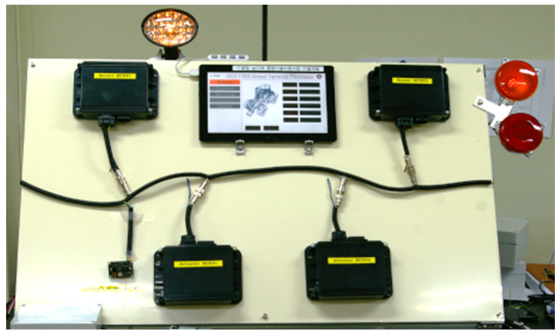


Figure 3. Demonstration of prototype configuration with related component.

The GPS message format is specified in the National Marine Electronics Association (NMEA) standard (NMEA 2000). In addition, the task controller is used to collect data during field operations for producing farm records.

Figure 2 illustrates an experimental configuration of the developed ISO 11783 application. Based on this schematic diagram, the prototype configuration of ISO 11783 compliant system was developed (Figure. 3). The application mainly consists of three components: a virtual terminal, a main ECU and two implemented ECUs handling lamps and receiving the information from a GPS receiver. A communication model among the three components was implemented based on the ISO 11783 specifications and the major parameters, including message type, message identifier and pay load, were parsed to the correspondent protocol data unit (PDU) format. Using a commercially available GPS receiver (UIGGUB02-ROO1, Uigoods Inc., Korea) has an error of 2.5 m in RMS, we expected that the comparative analysis between measured and real position would be possible to evaluation the transmission performance of the developed prototype. By embedding messages randomly generated by TECU into implement bus, the overall bus load was manipulated into higher update frequency than 4 Hz as noted by specifications provided by GPS receiver.

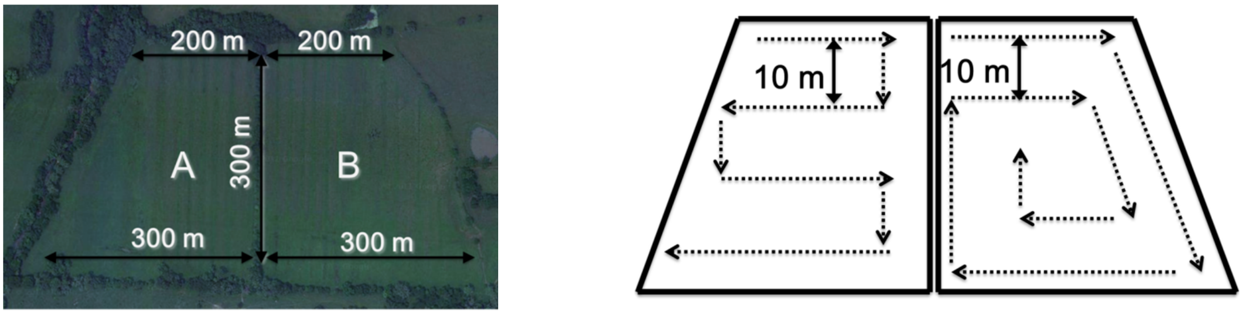
A basic function test was carried out to verify the proper operation of TECU communication with the main ECU and VT through CAN-based communication at laboratory. In common communication networks and integrated circuits, network throughput is defined as the average rate of successful message delivery over a communication channel expressed as the data transfer rate of useful and non-redundant information. Loss rate is defined as the ratio of lost messages to total messages sent. To measure the transmission performance of the implemented communication network, throughput and loss rate were calculated across the range of bus load from 10% to 100%.

Experimental field test

Accurate monitoring of an agricultural vehicle's position is one of the most important factors for implementation of TECU. This information could be obtained from a relative difference (e.g. a laser elevation sensor) to an absolute indication (e.g. geological coordination). A commercial GPS receiver could give us the geological coordination with some amount of error designated by the operation of satellites. For an application of TECU requiring the higher precision of position information, the more accurate GPS receiver would be strongly recommended. On the contrary, regardless of the precision of the GPS receiver, the performance of other component in the prototype must be carefully considered. For example, the presence of a very high latency time or a high rate of error in the communication among the devices could lead us to the failure of a designed transmission performance. Therefore, a customized implementation of communication network based on ISO 11783 should be proved to be suitable to satisfy 250 kbps of transmission rate recommended for TECU.

To evaluate the implemented prototype, experimental field tests were performed in a test field. The test field consists of two part (Fig. 4(a)) topologically symmetric along the horizontal direction. The dimension of each test field was 300 m × 300 m × 200 × (bottom length × top). Traveling methods in each sub field has slightly different direction and distance as shown in Figure 4(b). The ground speed of travelling was approximately maintained as 0.5 m/s, 1 m/s, 1.5 m/s and 2 m/s by manual operation.

During travelling the test field, information collected from the GPS receiver was transmitted to the TECU and converted into a PDU format to be transferred to the main



(a) (b)

Figure 4. The experimental field dimension (a) and an illustration of travelling (b).

ECU. The main ECU analyzed the transmitted data on GPS positioning information. After storing the information to the main memory, VT displays the position of the vehicle in real-time. A comparative analysis between real world coordination and the processed coordination was done in accordance with the different system load called by "Bus load". As previously explained, to manipulate the bus load, random noise was generated from the TECU designed to receive GPS signal, and embedded into the transferring data packet. Changing the frequency of generating random noise, the overall bus road has variation from 10% to 100% of the systematic maximum throughput of 800 kbps provided by the test board.

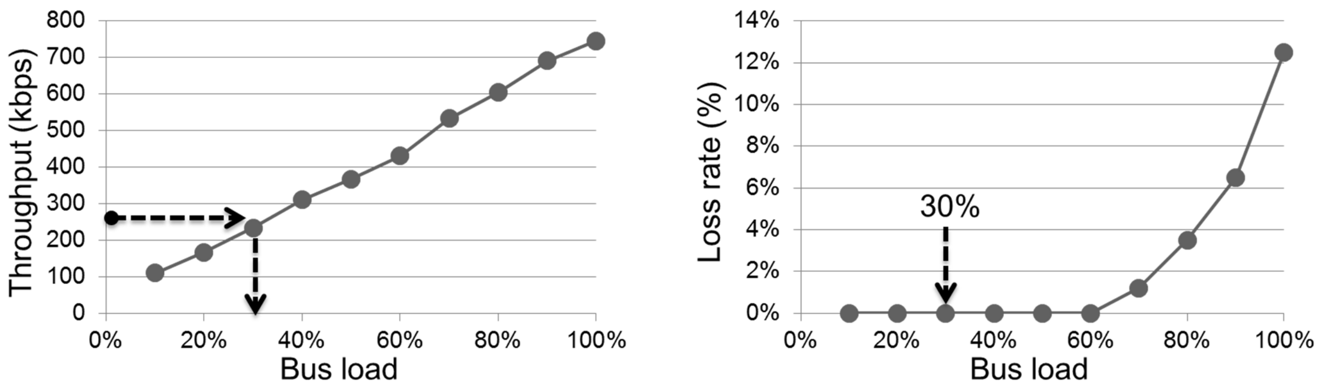
Results and Discussion

Results of throughputs obtained with the implemented communication network under different bus load conditions are shown in Figure 5(a). A horizontal dashed arrow starts from 250 kbps of bus speed as recommended by ISO 11783, then 30% of bus load was approximately identified in compliance with ISO 11783. Loss rate at 30% of bus load was zero as shown in Figure 5(b). This result from basic function test provided a potential for actual field applications with the implemented prototype. However, the maximum throughput was lower than 60% of bus load.

To quantitatively compare the transmission performance of the test application, the root mean square of error (RMSE) between measured and real position was calculated. A geological inconsistency between the real world coordination and the processed coordination was regarded an error. The RMSE was obtained from experiments repeated 3 times with the different condition of travelling type (Fig. 4(b)) and travelling speed.

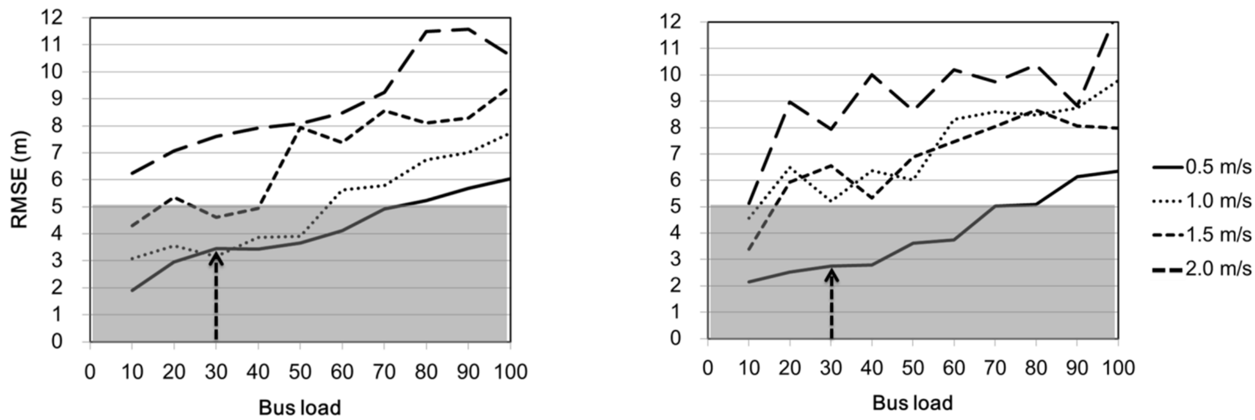
The resulted plots have two essential implications about the relationship between bus load and RMSE. One is that that bus load was clearly a dominant factor affecting the RMSE change. In other words, the high bus load would not be effective for various field operations requiring a relatively higher spatial resolution of position. The other is that the vehicle speed was also a factor causing errors not as much as bus load, meaning that the higher bus load and the faster vehicle speed would allow appropriate operation during field operations using the developed prototype. Nevertheless, considering the maximum requirement (30 %) of bus load found from the previous experiment (as indicated by a black dotted arrow in figure 6), the developed system with a travelling speed of 0.5 m/s could sufficiently correspond to the maximum requirement of ISO 11783 for both of the travel types. Considering the results with the faster vehicle's travelling speed than 0.5 m/s, RMSE exhibited the improper functionality of the developed application for most of the cases. Because an experiment with 0.5 m/s of travelling speed only resulted in a RMSE less than 5 m with both cases of travelling types. Particularly, in case with travelling at the sub-field A (Fig. 4(a)), the overall RMSE level was greater than at the sub-field A (Fig. 6). The difference between the two travel types would be due to the different amount of straight travelling. The length of straight travelling at the sub-field A was relatively longer than at the sub-field B. Even though there was no loss rate under 60% of bus load, RMSE of vehicle's position was approximately proportional to bus load. Because a transmitted message from an implemented TECU with GPS receiver was interfered by random messages which were increased by higher bus load.

In summary, the variance of RMSE due to the bus load and vehicle speed was clearly identified. While improper functionality of the developed prototype based upon the



(a) (b)

Figure 5. Result plots from the basis function test. Throughput (a) and loss rate (b) across the bus load.



(a) (b)

Figure 6. Result plots from the field test at sub-field A (a) and sub-field B (b). The grey region indicates the expectable limits with the GPS receiver.

compliance to ISO 11783 existed at higher than 60 % of bus load, the transmission performance at a travelling speed of 0.5 m/s was sufficiently correspondent to the maximum requirement (30 % of bus load) of the standard.

Conclusions

Throughput and loss rate of the developed prototype were calculated across manipulated bus load for laboratory experimental tests, and the maximum requirement of transmission rate by ISO 11873 was satisfied with lower than 60 % of bus load. Field tests with a TECU implemented to process messages from GPS receiver resulted that the root mean square error of vehicle's position was commonly lower than 4 m with 0.5 m/s as a travelling speed.

Referencing of the developed prototype based upon ISO 11783 could provide mandatory components those should be considered during the initial development step of agricultural machinery industries. The prototype fully implemented following ISO 11783 might be useful to design a solution with low integration effort during commercialization process in the agricultural machinery industry in the Republic of Korea. Further improvement and evaluation of the transmission performance of the developed prototype would be conducted with optimizations for more complicated field applications.

Conflict of Interest

The authors have no conflicting financial or other interests.

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