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Steer-by-Wire via ISOBUS

Satellite based navigation technology is a very challenging approach for the future automation of agricultural machinery. Integrating this technology into the mechanical, hydraulic and especially the electronic architecture of a machine is a safety-critical issue. Using the standardized electronic ISOBUS communication offers a broad range of advantages in modern tractors. Therefore, the capabilities of ISOBUS to be used for X-by-Wire applications are investigated from various viewpoints. Especially important properties of safe X-by-Wire applications like fault tolerance, real-time performance, dependability and others were focused on and assessed. Through an exemplary implementation of Steer-by-Wire architecture using ISOBUS, the theoretical considerations were realized and tested with very promising results.

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Literature

Literature references can be called up under LT 07SH24 via internet http://www.landwirtschaftsverlag.com/landtech/local/literatur.htm.

The introduction of automatic guidance systems based on satellite navigation was a great step towards robotics in agricultural tractors. This emphasizes the general trend of setting up systems, which allow more and more functions to be automated [1, 2].

A major prerequisite for the automation of functions is the interconnection of all basically self contained electronic systems in an agricultural working machine in order to realize a distributed electronic system. In the agricultural area, the ISO 11783 (ISOBUS) standard defines an open communication protocol at physical and application layer level and is based on the Controller Area Network (CAN) protocol [3].

X-by-Wire is a concept, where safety-critical operations of machines like steering or braking are fully implemented by electronic systems. The communication network is therefore the backbone of X-by-Wire applications and has essential requirements, which are mainly granted for time-triggered protocols [4].

The main objectives of this work are considerations about the integration of Steer-by-Wire functionality within ISOBUS networks based on CAN. For this, basic principles and requirements of safe, fault-tolerant, real time communication systems were analyzed.

Architecture for Steer-by-Wire

For innovations based on electronic equipment, it is the normal case that these systems are self-contained solutions at first. In the second or third generation, these systems become more and more integrated within the overall system architecture. This can also be assumed for the whole range of automatic navigation systems for agricultural machines. Most of the necessary components like the user interface, a navigation controller, a proportional hydraulic valve and a highly accurate GPS sensor are added to the tractor with no or just partial interconnection to the major electronic architecture of the tractor. Considering the first generation of automatic navigation systems, an integration of the navigation controller can be realized within the ISOBUS segment, where any communication is standardized and the Virtual Terminal (VT) can ideally be used as user interface.

ISOBUS is an open, runtime variable network with high requirements on communication safety and real-time capability. As shown in *Figure 1*, the steering angle setpoint has to travel through the ISOBUS segment to the Tractor ECU (T-ECU), acting as a gateway to the tractor internal bus segment before arriving at the steering control ECU. Because of the gateway, a chaining of several hardly predictable delays is the consequence.

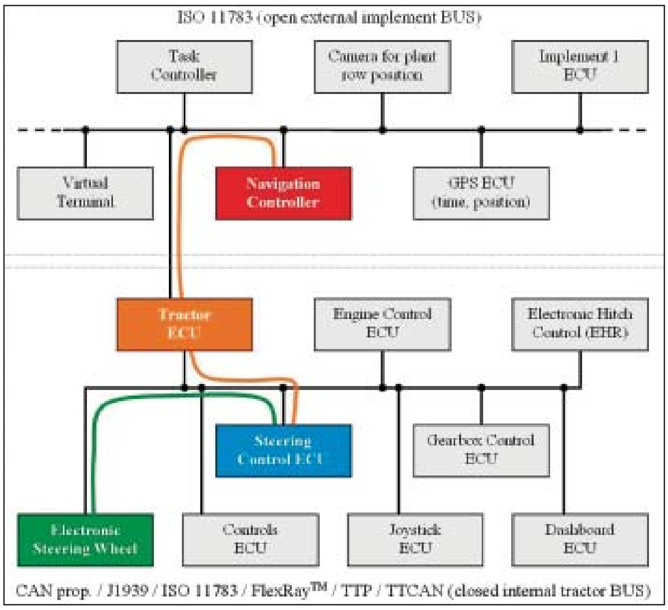

Fig. 1: Network topology with the Navigation Controller in the external ISOBUS segment

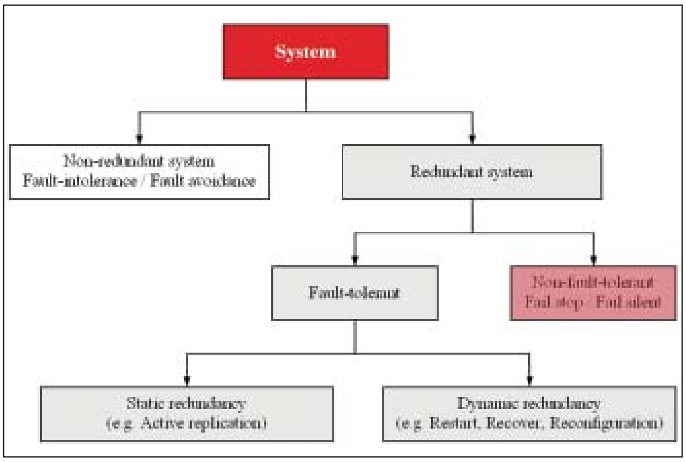

Fig. 2: System redundancy

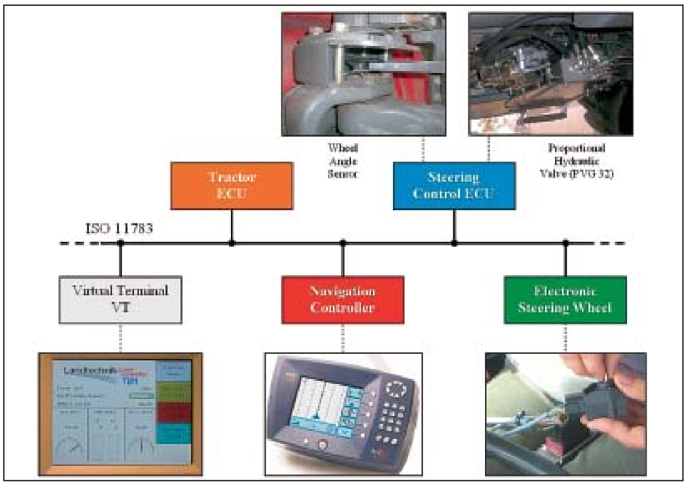

Fig. 3: Schematic network structure of Steer-by-Wire application via ISOBUS

X-by-Wire requirements

Safe X-by-Wire applications are capable to meet many important parameters like fault tolerance, real-time performance, dependability, flexibility, scalability and others [4].

When a system is redundant, it is possible to detect and handle errors in some way. The requirements towards the redundancy of a system are depicted in *Figure 2*. One main problem of ISOBUS is the lack of redundancy of the physical communication layer. CAN does not allow to drive two replicated channels, because of the error detection and immediate retry mechanism.

Also, real-time performance is claimed for X-by-Wire communication systems. In computer science, a real-time system has a time critical constraint i.e. operational deadlines from event to system response. A distinction can be made between those systems, which will suffer a critical failure, if time constraints are violated (hard real-time), and those which will not (soft real-time). A Steer-by-Wire application is considered to be hard-real time. Another requirement is the definition of the time within the system has to react.

ISOBUS is based on CAN being an event-triggered protocol. The arbitrating mechanism of CAN ensures that all messages are transferred according to the priority of their identifiers. This mechanism makes CAN very robust and provides high flexibility, but is not deterministic. The latency and jitter of a message with a certain priority at a certain time can not be guaranteed, whilst dependent of the overall system condition. For pure X-by-Wire systems, the transmission of safety-critical messages must even be deterministic at the maximum busload. Hence, the concept of time-triggered or hybrid protocols (time- and event-triggered) becomes essential.

Another important property is the possibility to guard the bus against non authorized bus access. This allows the active prevention of the occurrence of "babbling idiots" on the network.

Consequences for ISOBUS

Due to the physical and data link layer of CAN, it can be stated, that ISOBUS only allows creating a fail stop/silent system (*Fig. 2*, right). Therefore, ISOBUS can only be used to create X-by-Wire systems with mechanical or hydraulic backup, being categorized in Safety Integrity Level (SIL) 3 [5].

Suppositional, using high prioritized messages and a precise timeout detection of the navigation controller, ISOBUS should be able to provide real-time capability with 100 ms reaction time.

Another possibility to improve the timing behaviour of the overall system and to allow remote detection of failures in other nodes is to implement heartbeat. This is a timed mechanism using coarse synchronization.

The problem that a "babbling idiot" blocks the bus and thus prevents other nodes from sending cannot actively be eliminated in CAN networks. For a safety critical application, the only way to tackle this problem is to switch in fail silent mode and activate the redundant backslide layer.

Another safety-relevant issue emerges within the network management of ISOBUS. Each participant has to have an own and network wide unique source address. Because the source address in ISOBUS networks is assigned by a dynamic procedure and is not hard-wired within the logic of each controller, it is very simple for any node to send messages with another source address. This can cause severe failures in safety critical applications. One way to handle this problem is to monitor all member source addresses and to signal abuse.

Implementation of Steer-by-Wire via ISOBUS

A Steer-by-Wire application via ISOBUS was implemented and evaluated. All components of this test implementation were realized as ISOBUS compliant devices (*Fig. 3*). The system was fitted to a Fendt Vario 818, which already provides full ISOBUS functionality (T-ECU, VT). The steering control ECU was designed as a closed loop control system by using a wheel angle sensor and a PVG32 proportional hydraulic valve of Sauer Danfoss as actuator. The steering controller provides VT functionality and can fully be operated that way. Another ISOBUS compliant controller with VT capability is an electronic steering wheel with a potentiometer to produce dynamic set-point alternations.

The Steer-by-Wire relevant communication was achieved by sending changing wheel angle set-points by means of the electronic steering wheel. In order to address the mentioned safety-related issues, special communication mechanisms were implemented. A set-point sending routine of 10 Hz cycle time was established. In parallel, a special heartbeat mechanism among the steering control ECU and the electronic steering wheel was set-up at 5 Hz. An encryption/decryption algorithm was applied on the values of the eight data bytes of each heartbeat message [6]. This heartbeat mechanism serves on the one hand as a coarse synchronization and timeout mechanism, and ensures on the other, that both systems are vital and the sender surely uses its own source address. Alternatively, the ISOBUS NAME of both controllers was used for enhancing safety. After first feasibility tests, the system was comprehensive evaluated in field tests with up to 30 km/h driving speed. The system proved to stay fully operational without any interruptions under the given conditions.