CAN bus on-board control systems as the ideal first step in automating your mobile machines

Content:

Fast, reliable and intelligent data transfer is key in the automation and electrification of mobile machines and in off-highway vehicles. Electronic control systems and bus systems make a significant contribution in this respect. They exchange the data between the control components, and optimise and monitor themselves.

Introduction

Users of the machines are used to the devices from their personal life – smartphones, domestic appliances and TVs – having an intuitive and straightforward user interface, and this is something they also value at work.

This is a great sales argument for the OEM and, at the same time, guarantees user satisfaction. A user-friendly control system helps users to familiarise themselves with the machine more easily and reduces the number of errors made during operation. At the same time, the machine operators expect the work functions to be designed to be reliable and to use energy and oil resources efficiently. Thanks to the increasing use of electronic control systems, it is possible to implement these user requirements, and, moreover, to increase the level of safety for both the user and others working in the vicinity of the machine – no matter whether on a construction site, in a forest or on a field.

The agricultural machines that are ahead of the game

For a long time now, agricultural engineers have had the challenging task of finding a cross-manufacturer connection solution for tractors and attachment equipment, so that the user can also communicate with the attachment equipment from the operator's cab.

The bus system ISOBUS was developed for this very purpose – a cross-manufacturer solution for agricultural applications. A lot of manufacturers of agricultural machines use joysticks and/or displays in the operator's cab for operating the devices. As a result, functions and measurements from the tractor and the attached devices can be controlled and simultaneously read off one control unit. As all of the participants of the bus system can communicate with each another, they can be coordinated perfectly to one another. Recent advancements in the electronification of agricultural machinery has given rise to new possibilities – "precision agriculture" for example, whereby fertiliser and pesticides can

Smart farming stands for modern vehicle control in agricultural engineering (Image: Adobe Stock)

be distributed evenly and accurately using GPS data. The ISOBUS provides the means to process information locally from in-side the vehicle, as well as analyse and control it remotely. The various strands of data that stem from the tractor, attachment equipment, GPS location and steering systems are exchanged and processed in one network. Thus, manufacturers of agricultural machinery are early adopters of cross-manufacturer bus systems and all the advantages these bring.

However, there is also a growing trend within the mobile machinery and vehicle sectors to use intelligent, connectable, and easy-to-operate machines. By using electronic control systems, application-based software, and bus systems to create a network, it is possible to design be-spoke – yet at the same time, cross-manufacturer – solutions for all manner of applications. CAN buses, which have been established since 1992 and have been evolving ever since, have proven themselves the ideal solution in this respect.

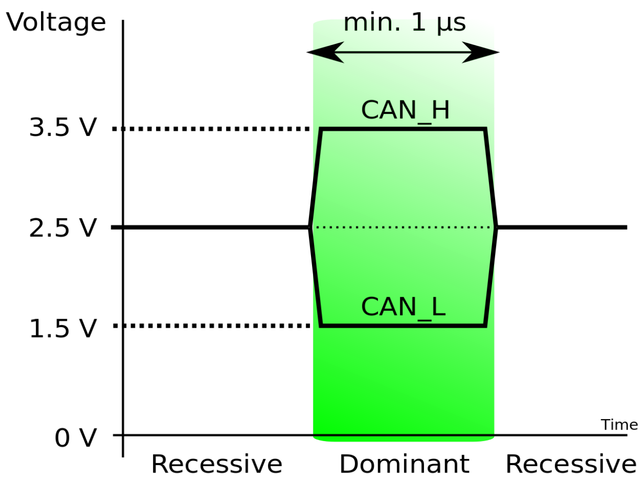
Why is the CAN bus ideal for the requirements of mobile machines?

Depending on the level of complexity, the electronic control system can be designed to be centralised or de-centralised – whichever option is of greater advantage. In both cases, a suit-able communication system is required to exchange the data between the decentrali-sed con-trol systems, the sensors and the actuators. In contrast to the well-known Universal Serial Bus (USB), which connects two devices with one another, the CAN bus enables the simultaneous connection of practically any number of participants – also called the nodes of the CAN bus. This means the CAN bus forms the starting point for the fast, specific, and reliable exchange of data within the electronic system of a vehicle, machi-nery or equipment. The use of CAN buses has become established not only in passenger and commercial ve-hicles, but in the en-tire mobile machinery sector, as well. Even in mobile hydraulics, more and more of the vehi-cles that have been launched to market have CAN bus technology.

This wide-spread bus system also offers increased, even greater immunity to interference, real-time reporting ability and all manner of diagnostics options. Electronic distance and colli-sion warning systems, like the ones used in passenger vehicles, are also being used more and more in mobile machines. This also includes ra-dar sensors, which help huge mobile machines to "see" their surroundings and blind spots more easily, and to detect obstacles. The data from these warning systems is fed to the main control unit by means of the CAN bus, and subse-quently transferred to the operator's cab or to mobile control devices for the user to view.

CAN = **C**ontroller **A**rea **N**etwork

The CAN bus is a robust, tried-and-tested bus technology that was developed by Bosch in 1983 and has been in commercial use since 1992. The CAN bus is a serial bus system from the fieldbus category, and it connects several participants with one another. When it was first developed, the initial idea was to reduce the length of cable harnesses – which had become immense (in the 1980s, the total cable length in a passenger car was over 2 km). Instead of having several dedica-ted analogue and digital signal lines, a two-core cable is used for digital data exchange, to which sensors or actuators can be connected directly via stubs or via addi-tional distribution nodes. The two-core CAN cable provides the significant advantage of ena-bling several sets of informa-tion to be exchanged within one line. Without this type of bus sys-tem, each set of information would require a separate cable. By reducing the number of ca-bles needed in the machine, it is not just weight and costs that are reduced.



Spannungspegel im Highspeed CAN-Bus (Bild: Wikimedia-Plupp)

With a CAN bus, data is transferred using just two cores. The two data lines are designated according to their si-gnal levels – as CAN_HIGH and CAN_LOW. The two lines contain the inverted and the non-inverted data signal (high interference immunity). The CAN network must be assigned a transfer rate that is identical for all parti-cipants. The maximum cable length depends on the bit rate, as all of the CAN nodes have to be able to process the message practically at the same time. In principle, bit rates up to 1 Mbit/s are possible.

When data is transferred in a CAN bus, the sender does not actually address any recipients (nodes). Each message is, in effect, sent to all participants at the same time and marked with a unique “identifier”. Furthermore, the identifier also determines the priority level of the message. All of the nodes in the CAN network use the identifier to check whether the received data is relevant for them. This means that messages can be received and analysed by several nodes at the same time. This type of message is called a “frame” and it consists of 7 characteristics: start condition, message identifier, control bits, data (0-8 bytes), check bits, acknowledge bit, stop condition. The frames are also differentiated by the length of the identifier: standard frame (11-bit identifier: 211 = 2048 addresses) and extended frame (29-bit iden-tifier: 229 = 536870912 addresses).

There are four types of message frames:

- Data frames (data transfer)
- Remote frames (request data frames)
- Error frames (signal bus error detection)
- Overload frames (create an additional delay between two data frames)*

Different protocol types are available, which define the use of the identifiers for specific types of messages and the format of the data bytes. The most well-known protocols are CANopen and J1939, which are also the most relevant for mobile machines.

* Source: Wikipedia

Why is it useful to have a CAN bus actuation directly at the directional valve (on-board)?

The use of electronics and the connection options for the controls and sensors in the machine via CAN bus result in the aforementioned advantages for the design of the control system and for the commissioning stage. These can be further increased by integrating the CAN bus node directly at the valve (on-board electronics). In the past, each valve section needed sepa-rate cabling, meaning that a valve battery that had to control, for example, 8 functions, would have needed 16 cables, all of which would have needed to be connected indivi-

The directional control valve with directly mounted CAN head as actuator is connected to the CAN bus only via a plug. (Image: HAWE Hydraulik)

dually to the valve control of the vehicle. If these separate valve sections are already connected with one another in the valve battery via a cable, all that remains to be done is to connect the complete valve battery to the CAN network with a connector. As a result, the level of cabling-related work required during the assembly and commissioning stages, as well as during servicing, is significantly reduced. This lowers costs and, at the same time, reduces the system’s susceptibility to errors. Plug connections in particular are one of the most frequent sources of errors in electric/electronic systems.

Accordingly, the number of PWM outputs on the corresponding electronic control system can – in principle – be reduced to zero. In theory, it is possible to connect any number of participants via the 2-wire line. Up to 40 valves can be controlled at once. This means that a bespoke solution can be devised for every customer.

How is the precision control range improved?

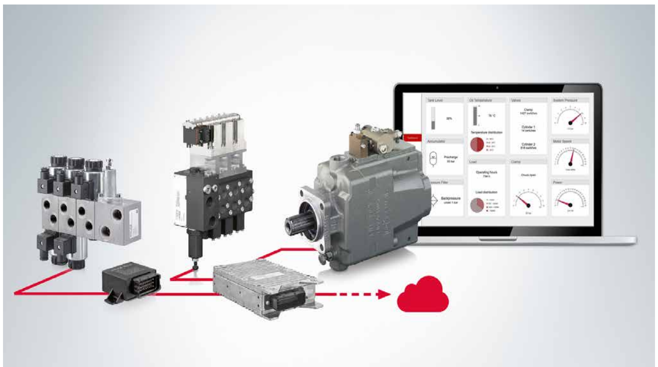
The precision control range of the directional valve has an important effect on the execution of the work function, especially when starting up the function or when high precision is key in the execution. This is defined through the curve of the flow rate based on the deflection of the joystick and, thus, the current, but influenced through the entire system. This flow rate char-acteristic curve can be adapted to the work cycle and the driver mode using the electronic control system, and, thus, readjusted and then fine-tuned during operation. The hysteresis of the directional valve plays an important role in this regard, as well.

The volume flow characteristic curve can be linearised by using onboard electronics. The start and end positions are preset on delivery. (Image: HAWE Hydraulik)

What diagnostics options are there with on-board electronics?

The on-board electronics provide excellent diagnostics options directly at the valve. Given that, in this case, the data is collected and analysed in a decentralised manner, there is less load on the main control unit, and the flow of data is reduced. As a result, you can read out, for example, the temperature, the solenoid resistance or the error status directly for the valve section in real time. It is also possible to electronically restrict the volumes handled at the individual valve sections or at the entire valve battery. An in-built position sensor permanently reports on the position of the valve spool on the control head and compares it with the set value. If there is a deviation, adjustments are made accordingly.

Further diagnostic possibilities are offered by forwarding the recorded data to the vehicle control system or to a monitoring solution in the cloud.



Recorded data can be stored, evaluated and readjusted either locally or centrally. (Image: HAWE Hydraulik)

Example:
Calculation of cabling work for a truck loading crane

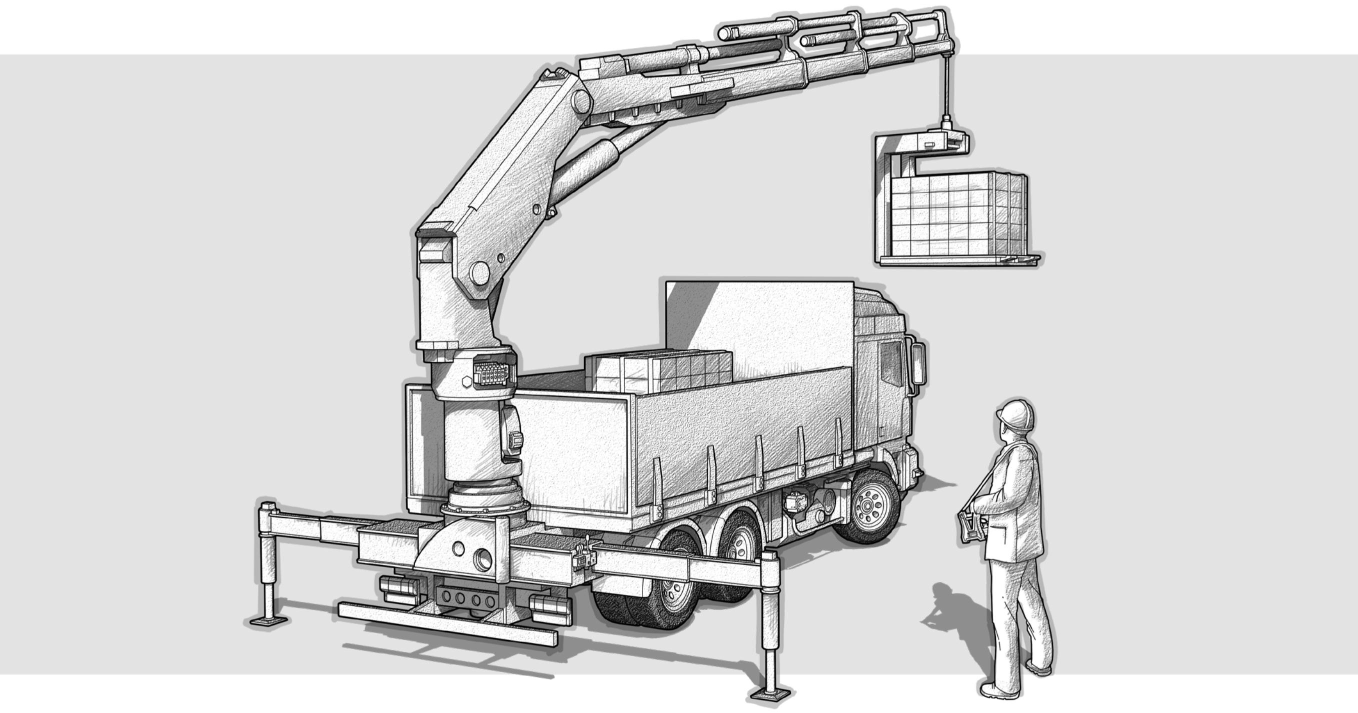
In a truck loading crane, different functions – such as the outrigger and the movements of the crane arm – are controlled hydraulically. Each individual movement, such as turning the arm, extending the boom, etc., is controlled by a separate valve section in the hydraulic valve bat-tery. For example, if a crane boom has 18 separate functions, all of which were previously controlled through PWM valves – now exchanged for CAN bus on-board valves – we arrive at the following example calculation.

The PWM valves are connected to the CAN bus of the vehicle by means of two cables per valve section. In contrast, the respective CAN bus on-board valve battery is connected to the vehicle control system by just one cable.

Based on 18 CAN bus valve sections for 18 separate functions in this example, it is possible to forgo the connection and laying of 36 cables and 5 distributor boxes. Even just by using fewer materials and needing less time for the installation, considerable cost savings can be made:

Component	Price	Number	Savings
M12 cabel	8,- €	36	288,- €
M12 Distributor box	120,- €	5	600,- €
Installation	60,- €/h	15h	900,- €
Total savings			1.788,-€

Sample calculation for a truck loading crane with 18 hydraulically controlled individual functions



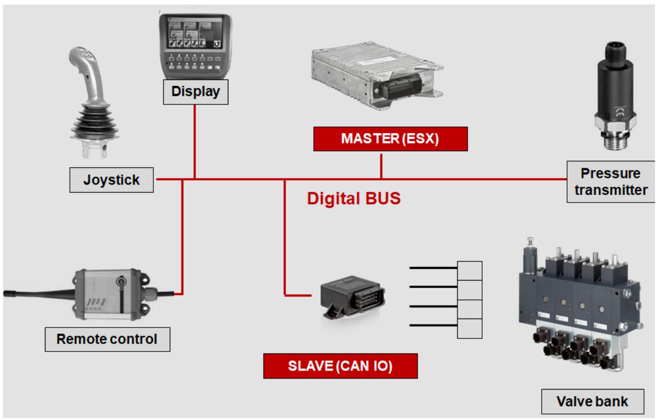
How do preconfigured parameters make the commissioning process easier?

A significant advantage of valves with on-board electronics is the "plug & perform" function. This means that customers can determine specific parameters in advance, such as firmware, baud rate, note ID, and the supplier can deliver the valve with precisely this preconfigured data for the commissioning stage. Thanks to the hydraulically preconfigured parameters for the valves, an initial parametrisation is no longer necessary, which saves even more time and money. As a result, these valve solutions don't require any more adjustments on the controller. All that is left to do is to install the valve batteries and connect them electrically and hydraulically. This means the time required for the commissioning and for configuring the current can be forgone completely. That is why these types of valves are ideal for series manufacturing, and the economies of time and money are a considerable advantage. In the case of valves without a corresponding on-board electronic system – so without the "plug & perform" function either – the start and end positions always have to be parametrised in the control system.

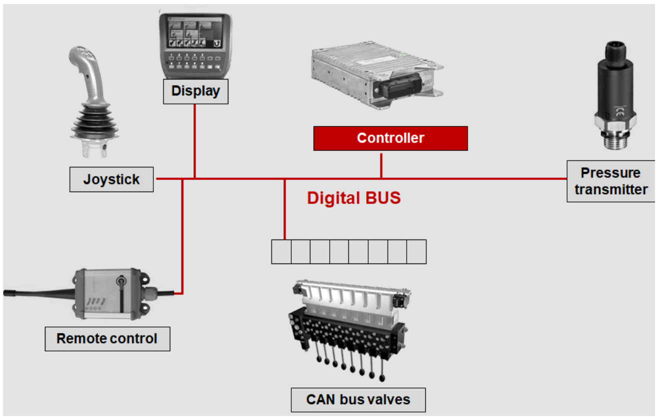
What else is needed for a control system designed using CAN bus technology?

To be able to create a complete control system with CAN bus communication, you also need a mobile control system with a CAN bus interface. If the vehicle already contains this type of control system, it can also be used for controlling the hydraulic valve batteries. All of the sensors and the actuators that are to be installed in the control system construction require a CAN bus interface.

The following figure depicts a decentralised control system architecture, which is usually implemented using a CAN bus communication system. The figure makes it clear that a main control unit (master) is required, to which additional decentralised I/O control units can be connected as slaves. In comparison, in a centralised control system architecture, all of the devices are connected to the main control unit individually. This is usually carried out via purely analogue and digital signals.



Example for the design of a decentralized controller with an IO module for connecting a directional control valve without CAN bus onboard (Image: HAWE Hydraulik)



Example for the design of a decentralized control with CAN bus actuation directly at the directional control valve. Only one connection is still necessary (Image: HAWE Hydraulik)

Mobile controller from HAWE Hydraulik:

HAWE Hydraulik offers various mobile control units in modular design and together with its partner STW. The most appropriate size is selected based on the complexity and the number of inputs and outputs. The CAN-IO-type I/O module is used as a decentralised CAN node. With its 8 inputs and outputs, it can be used for controlling the support or individual functions. If the requirements and number of inputs and outputs are higher, ESX-type mobile control units are used. The number of inputs and outputs determines how many sensors and actuators can be connected. The individual control unit types also differ in their level of processing power.

All of the ESX-type mobile control units can be freely programmed in different program development environments (e.g. CODESYS, LogiCAD) and with different programming languages like “C” or Structured Text (ST). HAWE supports machine manufacturers by providing finished software function blocks and an experienced Application team. The compact ESX-3CS-type control unit can be used as a central control unit for relatively small machines, or as one of several decentralised control units for larger machines. The ESX-3CM-type mobile control unit features SIL2, in preparation for meeting the various functional safety requirements.

	CAN IO 14+	ESX-3CS	ESX-3CM	ESX-3XL
Input	6x Analog or Digital	16x Analog or Digital	28x Analog or Digital	28x Analog or Digital (extendable to 100)
Output	4x IPWM + 4x PWM	14x IPWM	28x IPWM	24x IPWM (96)
Communication	1x CAN Bus, RS232	2x CAN Bus, RS232, opt. 1x Ethernet Diagnostic	4x CAN Bus, 1x RS232, opt. 1x Ethernet	4 (16)x CAN Bus, 1 (4)x RS232, opt. 3x Ethernet
Processor	Freescale, 20 MHz	TriCore, 32 bit, 300 MHz	TriCore, 32 bit, 300 MHz	TriCore, 32 bit, 150 MHz
Programming	C, eDesign, VT*	C, Codesys, LogiCAD, VT*	C, Codesys, LogiCAD, VT*	C, Codesys, LogiCAD

Overview of the range of electronic controls from HAWE Hydraulik's partnership with STW

The PSL-CAN: the directional valve with on-board CAN bus actuation from HAWE Hydraulik

HAWE Hydraulik offers the PSL-type proportional directional valves in three different sizes. The basis of the kit is a mechanically actuated mobile valve with a simple, analogue electrical control (pulse width modulation – PWM). The next two model variants to derive from this were equipped with a CAN head. Since 2010, HAWE has also offered a high-performance product – the PSL-CAN – which is even suitable for applications with requirements of high precision, hysteresis and dynamics. Furthermore, in 2019, a more cost-efficient CAN head, the PSL-CAN Lite, was developed as an entry-level model. Although this CAN bus valve does not offer the extremely high precision of the PSL-CAN, it enables the same easy connection to the CAN bus via a connector. It's functionality already suffices for a great number of applications and, thus, is an ideal option for venturing into CAN bus technology.

All actuation variants of the PSL can be combined in one valve battery if required. A hand lever actuation as manual override can easily be added. (Image: HAWE Hydraulik)

With the PSL-CAN Lite, the customer already fully benefits from the aforementioned advantages:

- Simple cabling
- Fast commissioning
- Electronic fine control range
- Simple and robust CAN communication
- Very good diagnostic possibilities

The high-performance PSL-CAN also contains spool position feedback and, as a result, is hysteresis-free and linearised. It is used in particular for applications that require high precision or fully automated, complex processes.

Various sizes can also be combined in a valve battery with CAN bus actuation. This makes it easy to adapt the volume flow to the requirements of the respective function. (Image: HAWE Hydraulik)

Prospects

The complexity of mobile machines and their degree of automation will continue to increase in the future. The main drivers behind this are the major trends of the present day and age: electrification, autonomous driving and remote controlling and diagnostics. On top of this, there is a growing volume of legislation and guidelines for improving safety.

Electrification will continue to increase the number of control systems and the level of processing power they require in vehicles and in the control centre. Autonomous driving and working is only possible through the use of additional sensors (RADAR, LIDAR, ultrasound, 2D cameras, 3D cameras) and the provision of further processing power. At the same time, the amount of data

Further developments in commercial vehicle construction drive the demand for fast communication within the vehicle control system and automation of work functions. (Bild: AdobeStock)

is increasing, which leads to a demand for more bandwidth in the bus systems. This is where the CAN bus reaches its limits. Faster bus systems, such as Ethernet and the BroadR-Reach variant, which also functions using a simple two-core cable, are possible solutions for the future instead.

However, when initially venturing into the automation of mobile machines and off-highway vehicles, the CAN bus will stand you in good stead. Thanks to its simple control system design and efficient communication method, as well as the many components available on the market, the CAN bus is a comparatively cost-efficient entry-level product.

However, the CAN bus also has more evolved versions. In 2012, Bosch presented the CAN-FD ("flexible data rate"). CAN-FD is meant to be able to increase the data rate to up to 15 Mbit/s. At the same time, up to 42 bytes of data are transferred per frame. There are also additional protocols for special applications. For example, the marine sector uses the NMEA protocol, and fire engines use FireCAN.

The electrification of mobile machines does not mean the end of hydraulic control. The hydraulic components have been transformed into intelligent, electronically controllable and energy-efficient components of electrified vehicles. The known advantages, such as power density and cost-efficiency, still apply in this case, as well.

In preparation for the future and for special applications, HAWE Hydraulik has been continuously evolving its products or entering strategic partnerships with leading technology companies. For example, HAWE Hydraulik and STW (Sensor-Technik Wiedemann) made their first public appearance as partners for developing integrated mechatronic drive solutions for mobile machines at the Hannover Messe 2018. Together, the two partners develop end-to-end systems from the hydraulics through to automation and Cloud-based concepts. With the takeover of Mattro in 2019, HAWE Hydraulik has acquired experienced experts in the electrification of complete vehicles, such as snowcats, lifting equipment and robot platforms. We are currently strategically expanding our knowledge, which will flow into the future development of hydraulics modules.

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