March 2019

CAN Newsletter

Hardware + Software + Tools + Engineering

Modularity

Hybrid walking and driving rover

Electric propulsion demonstrator for a battery-powered aircraft

Modularity without interoperability testing does not make sense

www.can-newsletter.org

Diagnostic Devices for CAN and CAN FD Buses

PCAN-Diag FD

Diagnosis at Physical and Protocol Levels

The PCAN-Diag FD is a mobile solution for the diagnosis of CAN and CAN FD buses. The oscilloscope specially designed for CAN allows an intuitive examination of individual frames.

- High-speed CAN connection (ISO 11898-2)
  - Complies with CAN specifications 2.0 A/B and FD
  - CAN bus connection via D-Sub, 9-pin (CiA® 303-1)
- Device operation via a push dial and 4 buttons
- Display with 800 x 480 pixel resolution
- Power supply via rechargeable batteries or a supply unit
- Clear display of the CAN traffic with various information
- Configurable symbolic message representation
- Transmitting individual messages or CAN frame sequences
- Recording of incoming CAN messages
- Playback of trace files with optional loop function
- Measurement of the CAN bus load and termination
- Voltage check at the CAN connector for pin 6 and 9
- Oscilloscope function for a qualitative assessment of the signal course on the CAN bus
  - Two independent measurement channels, each with a maximum sample rate of 100 MHz
  - Display of the CAN-High and the CAN-Low signals as well as the difference of both signals
  - Trigger configuration to various properties of CAN messages like frame start, CAN errors, or CAN ID

PCAN-MiniDiag FD

Compact Handheld for Basic Diagnosis

With the PCAN-MiniDiag FD, service technicians and developers can easily access CAN networks whose configuration is unknown. For this, the nominal bit rate for CAN and additionally the data bit rate for CAN FD are determined using bit timing measurement.

- High-speed CAN connection (ISO 11898-2)
  - Complies with CAN specifications 2.0 A/B and FD
  - CAN bus connection via D-Sub, 9-pin (CiA® 303-1)
- No influence to the CAN bus due to permanent listen-only mode
- OLED display with 128 x 128 pixel resolution
- Power supply via exchangeable batteries
- Operation via membrane keypad with four keys
- Plastic casing with increased Ingress Protection IP42
- Detection of bit rates via exact bit timing measurements
- Measurement of the CAN termination
- Measurement of the CAN bus load with display in diagram
- Voltage measurement for CAN-High and CAN-Low at the CAN connector (D-Sub) via pin 2 and 7
- Voltage check at pin 6 and 9 with display of the voltage difference
- Counter for CAN, CAN FD, and error frames

embeddedworld2019
Exhibition&Conference
... it's a smarter world

Meet us in hall **1**, booth **483**

PEAK-System Technik GmbH

Otto-Roehm-Str. 69, 64293 Darmstadt, Germany
Phone: +49 6151 8173-20 - Fax: +49 6151 8173-29
E-mail: info@peak-system.com

www.peak-system.com

PEAK System

Modularity

Imprint

Publisher
CAN in Automation GmbH
Kontumazgarten 3
DE-90429 Nuremberg

publications@can-cia.org
www.can-cia.org

Tel.: +49-911-928819-0
Fax: +49-911-928819-79

CEO
Reiner Zitzmann

AG Nürnberg 24338

Downloads December issue:
(retrieved February 20, 2019)
3793 full magazine

Editors
pr@can-cia.org

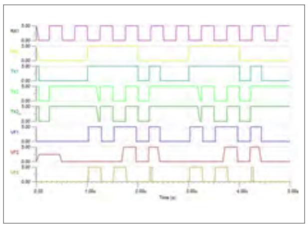
Cindy Weissmueller (cw)
Holger Zeltwanger (hz)
(responsible according
to the press law)

Layout
Nickel Plankermann

Media consultant
Gertraud Weber
(responsible according
to the press law)

Distribution manager
Gertraud Weber

Applications



Semiconductors

Engineering

Embedded World 2019

Annually, the embedded community meets at the exhibition center in Nuremberg for getting an overview on latest developments regarding embedded systems. The international trade show focuses exclusively on embedded technologies. Visitors meet in Nuremberg to get an overview latest product developments, innovations, and trends of the embedded sector. CAN in Automation (CiA) is as usual present with a stand at Embedded World (hall 1, stand 630). The tradeshow takes place in Nuremberg (Germany) from February 26 to February 28. CiA's main exhibition topic is CANopen FD. The fair is a good opportunity for members to discuss with CiA staff any topic regarding CAN technology and CAN markets. By the way, CiA provides new versions of its CANopen and CANopen FD posters. The stand is also a meeting point for members to network socially.

Hybrid walking and driving rover

The SherpaTT rover is equipped with a wheel drive and actuated suspension system. It is intended for planetary exploration and uses redundant embedded CAN networks.

Figure 1: SherpaTT driving through sandy dunes of the Moroccan desert; using the active ground adaption, it is possible to keep all wheels in ground contact to share the load of the vehicle; at the same time, the body is kept upright while passing varying inclines (Source: Florian Cordes, DKFI)

The DFKI German Research Center for Artificial Intelligence has developed the hybrid walking and driving rover. Recently, it was tested in the deserts of Morocco. The 200-kg robot was running new software enabling a 1300-m drive through sand and stones.

Using the actuated suspension system, it is possible to generate combined walking/driving motions and even short traverses of pure walking motion. The objective is to have an energy efficient (wheeled) locomotion that can be advanced in difficult situations using the active suspension or “legs” of the system. The SherpaTT rover was developed in a first version within the Rimres (reconfigurable integrated multi exploration system) project (2009 to 2012). The second version now active in various field trials was developed in the project Transterra (2013-2017). The tasks of both versions encompass the transportation of a walking scout robot and the transportation and assembly of scientific payloads.

Originally, the SherpaTT rover was not equipped with CAN networks. The researchers used their own LVDS-based (low-voltage differential signaling) communication system, also known TIA/EIA-644. “However, as a secondary aspect, we developed a version of the motor control electronics for a space qualification process in the project”, explained Florian Cordes from the DFKI. “This version is indeed equipped with a redundant CAN interface and is aspired to replace SherpaTT's motor control units in a future space qualified rover system.”

Intended for a Mars expedition

The deserts of Morocco close the border of Algeria are similar to the conditions on the Mars. In early December 2018, the two meters long SherpaTT robot was tested there. Some 30 scientists from eleven countries collected findings for the European Peraspera (Latin meaning: Through hardships to the stars) project. The rover with articulated legs is aspired to be used for the exploration of the red planet. In the test, the rover used new software, which enabled an autonomous long-distance travel over steep slopes and gorges as well as opportunistic science, meaning that the rover chose rocks to be further investigated on its own during the mission.

The tested SherpaTT prototype is not yet radiation-hardened and is not designed to withstand extreme temperatures. To achieve this, it will be equipped for example with redundant CANopen networks compliant with the ECSS-E-ST-50-15 specification.

In both versions, the rover features an active suspension system for increased maneuverability and a multi-purpose manipulator arm that can be used for both, manipulations and locomotion purposes. The suspension system is constructed from four independent legs each equipped with a wheel. It uses active and passive suspension on different scales. Flexible metal wheels are employed to cope with ground irregularities on a small scale and to provide high traction in soft soils. Springs in the lifting actuators of the rover form a kind of serial elastic actuator that copes with bigger irregularities below one wheel diameter (These springs are not present in the second version anymore). Big obstacles and body leveling in sloped terrain are dealt with by actively actuating the suspension system [1].

With the suspension redesign, a second lifting actuator was introduced, resulting in a knee in each leg. The linear actuators are installed in such a way that they experience tensional forces while the wheel has contact with the ground. This leads to a stiffer system compared to the ▷

Figure 2: SherpaTT on a rock covered patch of desert in Morocco; an autonomous traverse with a total distance of more than 1 km was successfully conducted in this terrain; path planning, obstacle avoidance and path following are completely calculated on board, without the need for interaction with a ground control station (Source: Jonathan Babel, DFKI)

original Sherpa design where the actuator has to provide a push-force and mechanical slackness leads to high position variance.

A set of modularized actuators of different power classes has been developed at DFKI, these modules are used for the Sherpa redesign, reducing the number of different actuators in the system for improved maintenance and control. For communication between the actuator modules and the central control electronics it is intended to apply CANopen networks based on the above-mentioned ESA specification.

Joints with redundant CAN networks

The DFKI-X joints used in the SherpaTT robot comprise torque optimized brushless DC motors. They are used in combination with a harmonic drive gearbox on a single hollow shaft. The direct coupling allows a stiff transition of the drive torque leading to a high level of accuracy and dynamics. To reach a high level of compactness Hall and temperature sensors are directly integrated in the motor unit. It is envisaged to combine both, the motor and the control electronics in one housing leading to a compact multi-purpose robotic joint for space applications. The motor electronics are designed to support an 80-W BLDC (brushless directed current) motor at 28 V_{DC}. The design approach is based on COTS (commercial off-the-shelf) products, which were specifically chosen to resist the space environment.

It contains a flash FPGA with MRAM (magnetic RAM) data storage, a GAN-FET (field-effect transistor) power stage, an analog-to-digital converter, a redundant CAN interface, Hall as well as BEMV commutation and includes redundancies and self-monitoring along with a latch-up protection for every function block. The FPGA as central processing unit is used within the joint to control the motor and perform data handling from all integrated sensors. This enables a system wide decentralized processing architecture with a CAN interface directly integrated in the joint. The used VHDL code is adopted from terrestrial applications and hence not considering single event upsets (SEU). An SEU is a change of state caused by one single ionizing particle (e.g. ions, electrons, or photons), which may happen in the outer space.

During a one-week test campaign the DFKI-X joint undertook a preliminary total ionizing dose (TID) and neutron radiation test. During those tests the motor was coupled to the mechanical load. Further tests including environmental testing for pre-qualification purposes have been performed already. Among others, this included tests against mechanical loads, thermal-vacuum, radiation, and EMC. The tests for qualification purposes were carried out using the updated DFKI-X motor and electronic units [2]. ◀

hz
based on information by DFKI

References

[1] Florian Cordes, Christian Oekermann, Ajish Babu, Daniel Kuehn, Tobias Stark, and Frank Kirchner (all DFKI): An active suspension system for a planetary rover

[2] Roland U. Sonsalla, Hendrik Hanff, Patrick Schoeberl, Tobias Stark, and Niklas A. Mulsow (all DFKI): DFKI-X: A novel, compact and highly integrated robotics joint for space applications

Biological pest control on the corn field

Figure 1: The height and the track width of the stilt tractor can be adapted to the height of growth and row spacing in the corn field (Source: Graf-Syteco)

A working group, in cooperation with a company has developed a special lightweight stilts tractor with hybrid drive for biological pest control on corn fields. For controlling the machine, a CAN-based unit is used.

Agricultural machinery must be optimally adapted to the conditions of use. Since no suitable machine was available for biological pest control on corn fields, a working group of the Institute for Mobile Systems of the Otto von Guericke University, Magdeburg in cooperation with the company Biocare has developed a special lightweight stilts tug. When controlling the machine, the machine builders rely on a control and operating unit from Graf-Syteco.

The European corn borer is a small butterfly that is feared as one of the most important pests in maize farming by farmers. It is estimated that every year it destroys up to 4 % of the corn crop. An environmentally friendly biological method of combating the European corn borer by the parasitic wasp Trichogramma brassicae has proven itself as an alternative to the use of insecticides for many years. The parasitic wasps are parasites that lay their eggs in those of the European corn borer and prevent their development to the caterpillar so effectively.

The company Biocare offers so-called Trichosafe balls for application in the maize field, in which eggs parasitized by the parasitic wasps are contained in different stages of development. After application on the field, the beneficial parasitic wasps that fight the European corn borer develop over a period of up to three weeks. However, the effect of biological pest control depends on the balls being deployed at the right time. And at that time, the corn has already reached a height of about 1,80 m - the application of the balls with a conventional farm tractor is therefore no longer possible without damaging the plants. Since the effective amount of the biological agent is only about 100 global hectare, drones can be used to deploy the balls. For larger acreage Biocare has developed a pneumatic ball-thrower as an attachment that can be mounted on a high-leg self-propelled sprayer. However, these are clearly oversized for the small quantities and therefore too expensive for this application.

The working group of Prof. Stephan Schmidt from the Institute of Mobile Systems of the Otto von Guericke University, Magdeburg, is working on a practicable and cost-effective solution. The machine builders have developed a lightweight vehicle that optimally meets the requirements of the application and at the same time is very cost-effective. Since the required payload of the so-called stilt tractor and thus the required driving performance are very low, instead of a hydraulic an electromechanical drive can be used. Since a purely electric drive cannot cover the requirement for operation of 16 hours per day, a variable concept of backup battery and an internal combustion engine is used as a range extender. The internal combustion engine used in this serial hybrid drive has only a small power, which means an additional weight reduction. "The powertrain is comparatively easy. Overall, we were able to realize a very efficient special machine, " Prof. Schmidt explained.

The geometric requirements on the stilts tractor result from the use in the cornfield with a height of the plants of up to 2 m. The vehicle body with the driver's seat and the other components, such as the pneumatic ball thrower, must be located above the corn rows. The track width of the narrow stilts with the wheels and the drives must be ▷

adjustable so that it can be adapted to different row spacing of the maize rows. In order to prevent the stilts tractor from tipping over hilly terrain, a minimum track width of 4 m is necessary. On the other hand, the vehicle has to collapse to transport dimensions of 3,5 m x 2 m x 3 m. "That's how we make sure," Prof. Schmidt explained, "that the user can easily transport it from one corn field to another on a standard vehicle trailer." The backup battery and the range extender can be removed from the vehicle for transport. With a travel speed of 12 km per hour and a working width of the pneumatic ball thrower of 30 m, the stilt tractor has an area capacity of up to 30 hectare per hour.

Sliding box profiles as a basis

The team around Prof. Schmidt has realized the prototype of the stilt tractor with a classic four-wheeled vehicle concept, with single-wheel steering in front and single-wheel drive in the rear. The drive must have high low-speed torque due to the high road surface resistance and low driving speed. The two rear wheels are each driven by a synchronous machine with two-stage gearbox, which consists of planetary gear and chain drive. Prof. Schmidt explained the advantages of this drive concept: "The speed and torque can be optimally adapted, and we also succeed in constructing the drive very narrowly."

In order to enable the adjustment of the width and the height of the vehicle, a base frame structure based on box profiles is used, which can be pushed together easily. External lifting devices or linear actuators ensure a partially automated adjustment. The driver's cab and the various attachments are mounted on the base frame.

IP65 CAN control unit

The components of the drives, the steering and the power supply are equipped with CAN interfaces. The CAN master is a D1520 control unit from Graf-Syteco. The compact device with a 7-inch touch display with a resolution of 800 pixels x 480 pixels is ideally suited for use in mobile work machines. According to Prof. Schmidt, the main advantage of the D1520 for this project is the high degree of protection: "IP65 is relatively rare in these devices - especially if you want a display." The current speed as well as information about the state of charge of the batteries is monitored. The display shows the essential information needed to operate the vehicle. The horizontal and vertical position of the sliding frame profiles is also displayed.

The bright display is easy to read even in direct sunlight. The D1520 has two CAN interfaces (ISO11898) that can communicate with all components on the vehicle. A USB interface serves as a programming interface, and additional interfaces such as J1939 are used to connect additional peripheral devices. "For example, we connected the analog joystick, which allows the operator to steer, accelerate and decelerate the vehicle," Prof. Schmidt explained. Other functions, such as the choice of direction of travel, are realized via the touch display. ▷

Figure 2: The control of the stilt tractor is realized with an operating and control unit of type D1520, to which an analog joystick is connected (Source: Graf-Syteco)

Figure 3: Installation of the drives in the institute workshop (Source: Graf-Syteco)

The ARM9 processor provides enough processing power to perform all the control and visualization tasks for the stilt tractor. In addition to the driving functions, this is above all the energy management. The controller monitors the state of charge of the batteries and the functions of the range extender. In critical conditions, for example, when the battery is discharged, the controller stops the machine. Programming the visualization for the D1520, the students of the Magdeburg working group used the software tool GSe-VISU supplied by Graf-Syteco. The control tasks were programmed in C. "Support from the service team at Graf-Syteco was a great help in software development," Prof. Schmidt recalled.

Fully automatic driving

Currently, still the driver has to control the stilt tractor manually. The working group around Prof. Schmidt is already working on equipping the vehicle with assisted and automatic driving functions. For this, suitable sensors must be able to observe the environment. In particular, the detection of the individual rows is paramount, since then an assisted steering assistance for tracking can be realized. This should allow the fatigue-free operation of the machine. In the next step, a function for automatic turning in the headland is planned, for which, however, an exact location of the stilt tractor within the corn field is necessary. The long-term future project of the mechanical engineers from Magdeburg is the fully automatic driving with automatic sequence tracking, reversing function as well as mechanisms for avoiding obstacles in the field. ◀

Author

Dr. Joerg Lantzsch
Agentur Dr. Lantzsch
info@drlantzsch.de
www.graf-syteco.de

Electric propulsion demonstrator for a battery-powered aircraft

Figure 1: Technicians at Scaled Composites in Mojave (CA) install a wing designed for electric motors onto a Tecnam P2006T to form the X-57 Maxwell battery-powered plane (Source: NASA)

NASA and several partner firms led by Empirical Systems Aerospace have worked on the X-57 Maxwell electric propulsion demonstrator, which uses several CANopen networks.

The X-57 is an experimental aircraft designed to demonstrate improved aircraft efficiency with a 3,5-times aero-propulsive efficiency gain at a "high-speed cruise" flight condition for comparable general aviation aircraft. In the first testing, some battery issues were detected. After fixing them, NASA has now approved the final of four planned phases of the X-57 program. These will include mounting the high-aspect-ratio wing, installing the high-lift and cruise motors, and performing flight demonstrations by late 2018 and early 2019.

The X-57 CAN-based command network is used to control the electric motors and provides aircraft health and status information. The higher-layer protocol complies with CANopen. Some connected devices transmit proprietary messages (CAN layer-2 approach). The command flow consists of throttle encoders (TEs), which digitize the existing Tecnam throttle lever positions and the electric motor controllers, which use this position as a torque target.

The NASA researchers selected the CAN protocol, because if offers various benefits including error detection, frame arbitration, multicast reception, and prioritization [1]. The configured CAN bit-rate is 1 Mbit/s. The CANopen application layer (CiA 301) was chosen because it enables the integration of CAN devices with proprietary messages.

The devices of the CANopen command network were selected based on robustness and interoperability. Because some devices use the CANopen application layer, precautions were taken to ensure the devices using proprietary messages do not interfere with the additional functionality of the CANopen devices. The CANopen protocol uses a portion of the ID field, four most significant bits of the 11-bit identifier, to indicate PDO and SDO protocols. By considering the PDO identifiers used by CANopen, and carefully selecting the IDs for proprietary messages, ID collisions were prevented.

Connected devices

The battery management system (BMS) is a custom solution built by Electric Power Systems (EPS). It uses the CANopen application layer with a customized profile to fit the X-57 CAN architecture. The BMS provides battery health and status information to the CANopen network, which can help convey relevant information to the pilot.

The CMC device is a custom solution provided by Joby Aviation (Santa Cruz, CA) and uses a CAN interface without CANopen. It controls the 10-kW lift motors and the 60-kW cruise motors. This distributed electric propulsion generates enough lift by blowing over the top of the wing to enable the airplane to take off. The motor controller communicates via CAN health and status information for itself and the motor, including torque, speed, and temperatures, that can be used to provide situational awareness to the pilot.

Motec's (Australia) synchronous versatile input module (SVIM) is an analog-to-digital converter that transmits the data on a CAN network. These modules collect data at high rates (5000 samples per second) and high resolution ▷

CAN-based battery management system

NASA and Empirical Systems Aerospace (ES Aero) selected Electric Power Systems (EPS) to supply the Energy Storage System (ESS) for the X-plane project dubbed the X-57 Maxwell. The objectives of the project are to reduce the energy consumption of the aircraft by deploying a distributed all-electric propulsion system. EPS provided the battery modules and the BCC-701 battery management system.

"We are thrilled to work with NASA, ES Aero, and the other industry partners on this ground breaking project," said Randy Dunn from EPS. "Our modular BCC-701 battery management system and its aviation grade Energy Producing Ion Core (EPIC) battery modules enable NASA to meet its objectives of having a highly reliable custom high-voltage battery." The system selected is suited for the NASA project as the BMS can quickly be configured to multiple chemistry types while maintaining the integrity of a DO311 design base. The BMS features three CAN interfaces, which report the status on every part of the system. It also sends warnings and potential problem information with the cells via the CAN networks.

(15-bit) synchronously with other modules as needed. For the X-57 application, these modules are used to record the blade pitch angle and temperatures associated with the CMCs and the motors. The size and capability to transmit on the CAN network make these devices useful in an EMI environment research capacity.

The Australian company also supplies the D175 full-color, customizable display. It is the main human machine interface between the pilot and the CANopen command bus. These screens show health and status information from the BMS, CMC, and TEs devices while also showing warnings and alarms based on the values from these devices. The screens are toggled with switch inputs incorporated into the display. Along with the situational awareness provided by this display, the screens provide additional information that aid in troubleshooting on the ground and quickly diagnosing problems in the air. The two main pages for the pilot are toggled using a simple switch, while an eight-position rotary switch enables access to the remaining pages. This setup allows 16 different pages with information about the health and status of various X-57 components.

The advanced central logger (ACL) by Motec works as the processor for the display. The logger collects all of the relevant signals, performs mathematical operations on them, and feeds the results to the display. As such, the logger is used to determine the health and status of the battery and motors and to provide any alarms or warnings to the pilot by way of the display. The ACL also controls the light-emitting diode (LED) lights on the D175 display that provide quick information to the pilot, such as battery state-of-charge (SOC) or emergency location. Finally, the ACL serves as the interpreter for the SVIMs. The SVIM transmits data via CAN in a proprietary format that is not easily interpreted by the instrumentation stack. Therefore, ▷

Figure 2: The embedded CAN networks in the X-57 Maxwell battery-powered aircraft use fiber-optic cables to reduce the susceptibility radiated EMI from the traction power bus (Source: NASA)

data that come from the SVIM are read by the ACL and then retransmitted to the command bus for the instrumentation stack to record. Since the instrumentation stack time-tags all the data being recorded, there is an inherent delay between the time when the SVIM transmits the data and the instrumentation stack records the data after ACL retransmission. This delay is acceptable because of the slow rate of change of the data being collected by the SVIM.

The two rotary throttle encoders by Baumer (Switzerland) are CANopen compliant. These devices measure rotation of the stock Tecnam throttle levers and put the data on the CAN network. Each device also has dual encoders to provide greater reliability.

Western Reserve Controls (WRC) located in Akron (OH) supplied the fiber optic bus extenders (FOBE). They were customized for X-57 by repackaging for fit and robustness requirements. These bus extenders convert the electrical signals on the copper CAN network to optical signals on fiber optic cables and convert them back to electrical signals on a copper segment closer to remote CAN devices. The distance of the CMCs from the rest of the CAN-connected devices, and their use of high current to run the motors, present a higher risk of EMI in the copper-based CAN segments. By separating the CAN segments with Fobes and fiber optic cables this risk is mitigated.

The CAN-connected relay box by Blink Marine (Italy) enables relays to be opened and to be closed by means of CAN messages. This provides an audio annunciator capability that can provide key alarms to the X-57 pilot. These alarms are defined collaboratively with the test pilots, system designers, and operations team. The audio annunciator works by grounding specific inputs to the device, resulting in output in the form of an audio message. CAN messages from the ACL to the relay box energize relays, which completes the circuit to the annunciator, allowing the ACL to determine any alarm states and to alert the pilot both audibly (through the audio annunciator) and visually (through the D175 display). The audio annunciator that uses the relay box is a PRD60 accessory device developed by ▷

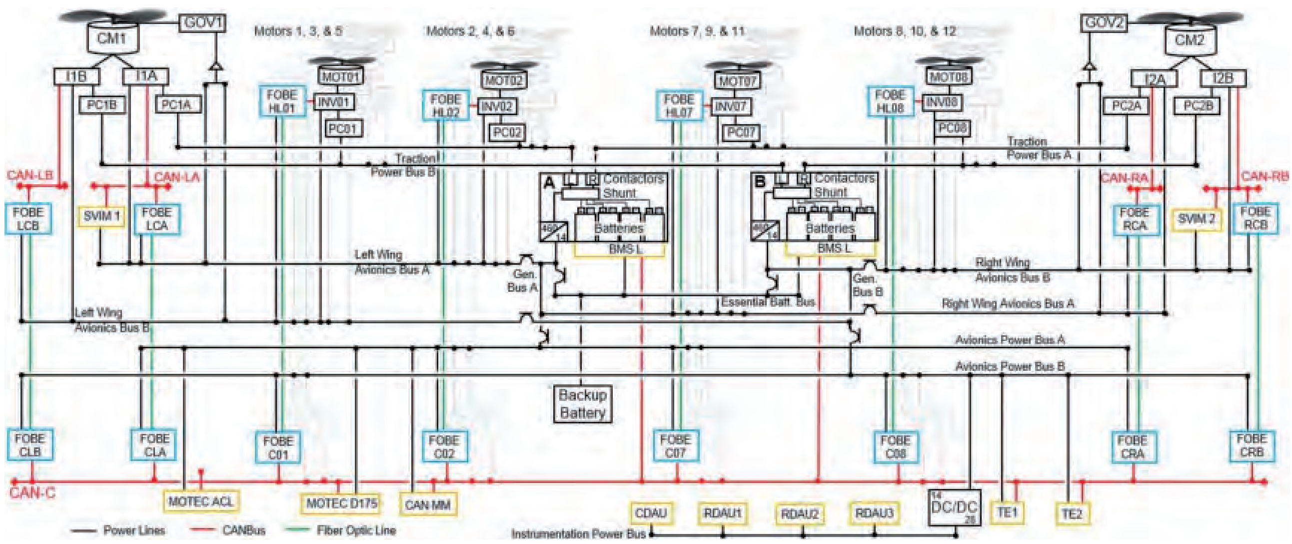


Figure 3: Block diagram of the X-57 command system network system, with commercial off-the-shelf (COTS) CAN segments (Source: NASA)

Figure 4: The ACL logger communicates via CAN with multiple SVIM input modules (Source: Motec)

PS Engineering (Lenoir City, TN). The device contains six pre-programmed messages and the ability to mute messages by acknowledging them with a simple push-button.

The X-57 instrumentation system contains a CAN network monitoring card that is linked to the command system. This card is used to only listen to the traffic on the CAN network and to record all of that traffic with a time tag. A subset of these messages is also transmitted to the ground station.

Risk mitigation

The X-57 CANopen command bus is considered a mission-critical system, but not a safety-critical system. This designation is possible because the pilot does not need to rely on the bus system for the safe operation of the X-57 flight demonstrator aircraft. All of the safety-related information provided by the CAN network is also independently measured and displayed on the right-hand instrument panel in the cockpit. The X-57 aircraft is also designed with an unpowered reversion mode, in which the pilot can safely control the aircraft and complete an unpowered, higher speed landing. This capability is facilitated by limiting flight to the area over Rogers' dry lakebed (Edwards, California), which provides ample landing options.

Although the command system itself is not safety-critical, the CMC and BMS, which are safety-critical devices, do interface with the CAN network. A bus failure for the X-57 flight demonstrator aircraft could result in a loss of communication to and from the mentioned safety-critical devices. Therefore, the BMS and CMC are designed to behave in a safe manner in case of bus failure. The BMS operates independently and only reports health and status to the network. It also reports operational status directly to the independent annunciator panel in the cockpit. The CMC, however, relies on command inputs received via CAN, so the CMC includes safety features to allow safe operation of the X-57 aircraft in spite of command bus interruption. If a command is lost from the throttle encoders, an internal

X-57 partners

- Baumer
- Blink Marine
- Electric Power Systems
- Joby Aviation
- Motec
- Tecnam
- Western Reserve Controls

CMC counter increments. During an initial count-up period, the last verified torque command is held and executed by the CMC. After a preset time, the CMC will execute a gradual ramp-down of the commanded torque to idle. These features enable continued operation for a short time after a bus failure. The preset timeout prevents an indefinite running of the motors in the case of ground testing, when the aircraft is being operated remotely. As a mission-critical system, additional measures are taken to reduce the risk of various command bus failures.

While the CAN physical layer makes the command bus resistant to EMI, steps are taken to further reduce the risk of the high-power systems introducing electric noise into the network. Mod II to the X-57 aircraft locates the CMC and motors in the same location as the original Tecnam engines. Mod III to the X-57 aircraft, however, requires the command bus to extend to that point. As such, the Fobes are used to incorporate the fiber optic cable segment between the fuselage and the CMC for both Mod II and Mod III. These Fobes operate in such a way that they are invisible to the devices on the CAN networks. The devices on either end of the fiber optic link behave no differently than if they were all connected by way of a copper cable.

To reduce the risk of throttle command failure, the throttle encoders used to measure the angle of the Tecnam throttle levers contain a redundant encoder. The encoder transmits the measurement from each encoder onto the CAN network. The device that read this information can then act on any discrepancies between the data reported by each encoder. A discrepancy between the two encoders is a case wherein which the CMC considers the incoming command as invalid and revert to the command bus failure mode, as described above. Further risk mitigation for the throttle encoders involves the physical device. The initial design to digitize the throttle position used a cable-pull encoder. This method was revised to use a rotary encoder that has a direct mechanical connection to the throttle levers to reduce the chance of the cable snagging.

The CAN physical layer provides redundancy for the motor commands. The data from each throttle encoder go to two CMCs on each side of the aircraft. To prevent a complete failure on one side in the case of a physical break of the CAN-based command bus, the physical tie-in of each CMC connected to the same motor is located on opposite ends of the network. Therefore, a break on one side of the CAN network ensures a physical path from the throttle encoders to at least one CMC on each side. ◀

hz

This article is based on the content of [1].

References

[1] Sean Clarke, P.E., Matthew Redifer, Kurt Papathakis, Aamod Samuel (all NASA Armstrong Flight Research Center), and Trevor Foster (Empirical Systems Aerospace): X-57 power and command system design, NASA 2017.

Service robotics for the nursing sector

As part of the Serodi project (Service Robotics for Personal Services), Fraunhofer IPA (Germany) collaborated with other research and application partners to develop service robotics solutions for the nursing sector.

Figure 1: The "intelligent care cart" uses some modules of the Care-o-Robot IV platform (Source: IPA Fraunhofer)

Service robots in healthcare are gaining importance. In the European Serodi project, "intelligent care carts" and the "robotic service assistants" were used in real-world trials in a hospital and at two care homes. This enabled the project partners to confirm the benefits of the robots for reducing the workload of nursing staff.

Not enough nurses for too many patients or residents: this is a familiar problem in the nursing sector. To address this, there is a need for solutions that not only reduce the physical and information-management workload of the staff, but also free them up to spend more time with those in need of care. The use of state-of-the-art nursing aids to assist the staff also makes it possible to add to the attraction of the nursing profession while maintaining an adequate quality of care also under challenging conditions. This is where service robots of the kind developed by Fraunhofer IPA and its partners under the Serodi project can be of benefit. The project received funding from the German Federal Ministry for Education and Research.

"Intelligent care cart" summoned at the press of a button

To cut down the legwork of the nursing staff and reduce the time spent keeping manual records of the consumption of medical supplies, Fraunhofer IPA in collaboration with the MLR company developed the "intelligent care cart". Using a smartphone, the nurse is able to summon the care cart to the desired room, whereupon it makes its own way there. ▷

Figure 2: The robotic service assistant is capable of operating in common rooms at care homes and hospitals, where it serves drinks and snacks to the residents or patients (Source: IPA Fraunhofer)

Being of modular design, the care cart can be adapted to different application scenarios and practical requirements. While it served for the transport of laundry items at the care homes, it was used to carry wound treatment materials in the hospital. A further feature of the “intelligent care cart”: it was always locked, the nurse opening it by logging in on the tablet. This also made it possible for the care cart to transport items that would otherwise have to be stored in a locked room and fetched only when needed.

The “intelligent care cart” makes its own way to the desired room and is also capable of using a lift. The nurse can summon it from a smartphone, which means less legwork for staff.

If the room is on a different floor, the care cart can use the lift. A 3D sensor along with object recognition software enables the care cart to automatically register the consumption of medical supplies. If an item is running low or the battery needs recharging, the care cart travels autonomously to the storage area or charging station once this the staff has approved.

Testing in coordinated real-world trials

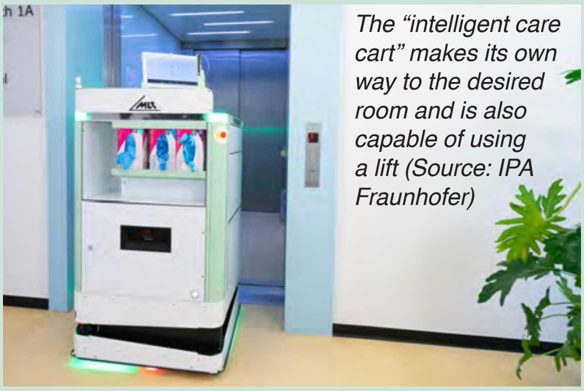
The care carts developed as part of the project were used in two coordinated multi-week trials at the participating establishments in Mannheim (Germany), the University Clinic as well as the Waldhof and the ▷

Service robotics for person-related services

Fraunhofer IPA has developed two robot solutions for inpatient care as part of the Serodi project. The aim of both is to relieve the strain on staff and thus give them more freedom for the actual care activities. The "intelligent care cart" navigates autonomously, i.e. the nurse can order it to the desired location via smartphone, thus saving long walking distances. The automatic recognition of the removed objects also reduces the effort required for the manual documentation of used care utensils. The second robot in the practical test was the "robotic service assistant". It also navigates autonomously in common rooms, recognizes people and offers them drinks. Here too, the use of robots is intended to relieve the strain on staff and increases the residents' fluid intake through regular reminders, as well as promoting their independence.

The care cart uses the mobile platform of the Care-O-bot 4 service robot (see also the article in the March issue of CAN Newsletter 2016) with a new body that can be stocked with care utensils. The mobile platform uses for low-level communication CANopen networks.

If the care cart is connected to the call system of the care home or hospital, it can travel automatically to the room from which the patient has rung. The built-in touchscreen allows the care staff to confirm their presence and, once the robot is no longer required, to free it up for its next assignment.



The "intelligent care cart" makes its own way to the desired room and is also capable of using a lift (Source: IPA Fraunhofer)

Some service robot sub-systems use embedded CANopen networks in conjunction with ROS (Robot Operating System) software. The open source ROS (BSD license) comprises libraries and tools to help software developers create robot applications. They can be downloaded from the ROS website. It provides hardware abstraction, device drivers, libraries, visualizers, message passing, package management, and more. The CANopen library of ROS complies with CiA 301. It features a high-level object dictionary for all simple types (except Boolean), SDO client function, PDO subscriber/publisher capability, EMCY handling, and NMT with Heartbeat support. Node-guarding is not supported. A plug-in provides node synchronization my means of SYNC services. To simplify system design, the parser for EDS/DCF compliant with CiA 306 can be used. A library for CiA 402 compliant motion controllers is also available.

hz

Figure 3: The service assistant can hold up to 28 cups or various snacks (Source: IPA Fraunhofer)

Ida Scipio senior citizens' homes. Whereas, at the care homes, the robot was stocked with laundry items directly by the nursing staff on the ward, the care cart used at the University Clinic was integrated into the hospital's extensive logistical processes. The modular baskets containing the dressing materials were restocked at the hospital's central logistics facility and sent to the wards, which meant that all the nursing staff had to do was to replace empty baskets with pre-packaged ones, with no need to put all the items together themselves. To further reduce the workload of the staff, Fraunhofer IPA is currently working on a solution also to automate the changing of the modular baskets.

Findings from the trials

One important finding from the real-world trials concerned the navigation of the care cart. As the "intelligent care cart" is based on the navigation processes of a driverless transport vehicle, it travels primarily along fixed predefined paths. For use in public spaces, it is possible to make minor deviations from these paths in order, for example, to dynamically negotiate obstacles in the way. The real-world trials revealed that efficient navigation requires extensive knowledge of the internal processes in order, among other things, to guarantee that the desired destination is actually accessible.

The initial trials also showed that it makes a difference whether the corridors have a single lane for both directions or separate lanes, i.e. one for each direction. A single lane proved more advantageous, as it was then unnecessary to keep so much space clear along the narrow corridors – even if this meant the robot not stopping immediately outside every room and sometimes having to travel with the drawers towards the wall and not turning until at the destination. For the residents and staff, however, this made it clearer where the robot was going. In addition, restricting the care carts to a single lane ensured that they did not have to make major detours in order, for example, to switch from one side of the corridor to the other.

The robotic service assistant is capable of operating in common rooms at care homes and hospitals, where it serves drinks and snacks to the residents or patients. ▷

Robot arm as well as control and operator module

The service robotics modules support the open source ROS software framework and the control module features CANopen functionality (Source: Pilz)

Pilz (Germany) has expanded its product portfolio by sub-systems for service robots. The products include initially the robot arm, the control module and the operator module. The essential features are openness, i.e. due to the open source ROS (Robot Operating System) software, user-friendly operation and fast commissioning according to the plug-and-play principle.

Robot arm, control module, and operator module together form a package certified by the German statutory accident insurance association (DGUV) in accordance with EN ISO 10218-1 "Robots and robotic devices" and they provide the requirements for the implementation of safe robot applications. This simplifies the way to the obligatory CE marking. The areas of application also include pick-and-place applications and modular semi-automated small robot cells in industry.

The robot arm enables a machine load of 6 kg. Due to six aces, a weight of 20 kg and a $24\text{-}V_{DC}$ voltage supply it is suitable for use in mobile applications, for example combined with an automatic guided vehicle (AGV).

The PRCM (Pilz robot control module) unit takes care of the movement and safety control of the robot. With the plug-and-play capability, users can connect the modules and use them without configuration. The control module supports CANopen and other communication networks. The PRCM unit can be programmed with PLC (programmable logic controller) languages compliant with IEC 61131-3 and via the ROS framework.

Pilz developed software modules for the control of robots based on the ROS software framework. This software offers functions for sensor processing, evaluation, planning, and controlling of robots.

The PRTM operator module enables the operation of the robot via a graphical user interface, due to an operator and visualization system developed by Pilz. The panel offers the functions of operating mode selection, emergency stop and diagnostics. It permits setup and teaching of the robot arm via a sensitive touch display.

"Pilz is a technology company that offers complete solutions for safe robotics", explained Susanne Kunschert from Pilz. "As a system supplier for service robotics, we can support users when implementing their individual robot applications, including the requires safe sensor technology and the required services on the way to CE marking", she added. *hz*

This not only reduces the workload of the staff, but also promotes the independence of those in need of care.

Evaluating the real-world trials, the participating nursing staff confirmed that, by reducing the amount of legwork, along with the associated timesaving, the “intelligent care cart” represents a potential benefit in their day-to-day work. Also, the faster provision of care, with no interruptions for restocking the care cart, results in an improvement in quality for patients and residents. The nursing staff described the control of the care cart using a smartphone and touch screen as straightforward. In addition to the nursing staff, the residents and patients as well as their relatives showed great interest in the new technology. “Having hit upon the idea of an “intelligent care cart” already some years ago, and with many potential users having shown great interest in the idea, I was delighted finally to see the care cart in operation as part of the Serodi project in the corridors of the hospital and care homes,” emphasizes Dr. Birgit Graf, who heads the Domestic and Personal Robotics group at Fraunhofer IPA.

Robotic service assistant serves drinks to residents

Alongside the “intelligent care cart”, the robotic service assistant is another result of the Serodi project. Stocked with up to 28 drinks or snacks, the mobile robot is capable of serving them to patients or residents. Once again, the goal is to reduce the workload of the staff, in addition to improving the hydration of the residents by means of regular reminders. Using the robot also has the potential to promote the independence of those in need of care.

At the Waldhof home for elder people, where the robotic service assistant was trialed for one week in a common room, it made for a welcome change, with many residents being both curious and interested. Using the robot’s touch screen, they were able to select from a choice of drinks, which were then served to them by the robot. The service assistant can hold up to 28 cups or various snacks. Once all the supplies had been used up, the service assistant returned to the kitchen, where the staff restocked robot before being sent back to the day room by the use of a smartphone.

This robot, too, received great interest from the participating nursing staff, who also discussed a host of possible improvements and additions to the robot in the course of the trial. Interaction with the residents was successful in the majority of cases, it merely sometimes being necessary for them to be shown how to use the touch screen. The synthesized voice of the robot was especially popular and even motivated the residents to converse with the robot.

The service assistant can recognize individuals, take up a position next to them and serve them with a drink while making use of its synthesized voice. The patients or residents can use the touch screen to select a drink, which they then take from the delivery compartment.

Results of trials pave the way for further improvements

“For us, the real-world trials provided valuable knowledge, enabling us to further optimize the robots and even better adapt them to the needs of users,” said Graf, summing up. For instance, the Serodi project has given a major boost to the use of new robotic solutions in the nursing sector. The medium-term goal is to make the improved prototypes ready for series production in collaboration with interested companies. At the same time, Fraunhofer IPA is continuing its long-standing work to open up new applications, including the development of robotic solutions for the nursing sector. ◀

hz

CAN Newsletter Online

Service robots

ROS and CANopen make a perfect team

Nanotec (Germany) has adapted the Robot Operating System (ROS) to its motion control products.

Read on

Hannover Messe 2017

Bionic robot arm with CAN

At the fair, Festo presents its Bioniccobot based on the human arm not only in terms of its anatomical construction. Seven absolute CAN encoders are used in the robot arm.

Read on

Humanoid robot

Biped robot for research with 10 CAN ports

REEM-C is a life size humanoid robot developed by PAL Robotics to serve as a research platform for universities and research institutions. The robot has ten CAN interfaces.

Read on

Self-driving system

Robots take over logistics

The Toru picker robot from Magazino features micro drives and motion controllers from Faulhaber. The used motion control system supports CiA 301 and CiA 305 as well as CiA 402.

Read on

Mobile robot

Carrying up to 200 kg

Mobile Industrial Robots (DK) has developed the MiR200 autonomous driving robot. It features CAN connectivity to add modules.

Read on

TTControl
HYDAC INTERNATIONAL

TTConnect Cloud Service

TTControl Cloud Service enables manufacturers of off-highway machinery, fleet owners and end customers to access machine data from the office, at home or on mobile devices.

The solution includes an easy to operate and intuitive cloud platform with a customizable front end PC-software, connectivity and a ruggedized hardware (IoT gateway) for a true end-to-end machine management solution.

The IoT gateway, TTConnect Wave, supports the industry standards CAN and Ethernet and additionally provides wireless and cellular interfaces to communicate with the cloud platform.

www.ttcontrol.com/Cloud-Service

Chipset for electric power steering

Infineon offers a chipset for upcoming EPS generations that includes semiconductor components such as power supply, micro-controllers, half-bridge drivers, Mosfets, CAN transceivers, and sensors.

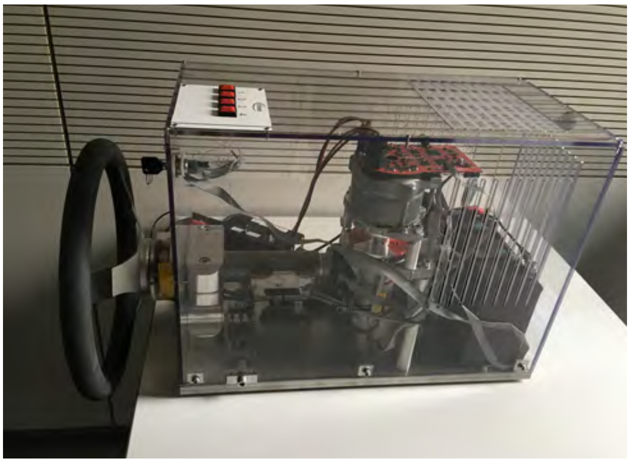


Figure 1: Demonstrator for an electric power steering application (Source: Infineon)

Electric power steering (EPS) has almost completely replaced hydraulic and electro-hydraulic systems. The advantages are obvious: They include higher energy efficiency, as there is no need for a constantly working, belt-driven pump. In addition, eliminating the hydraulic components simplifies manufacturing and maintenance. However, a reliable and efficient electric power steering system requires fine-tuned solutions based on powerful semiconductors. Infineon offers a chipset for upcoming EPS generations that includes all major semiconductor components such as power supply, microcontrollers, half-bridge drivers, Mosfets, CAN transceivers, and sensors. All of these components are already available. From a single supplier, customers receive everything included in a fine-tuned chipset, which will help to reduce development time and thus costs.

Electric power steering uses an electrically controlled motor as steering assistance. Sensors detect the steering torque triggered by the driver and forward the information to an electronic control unit (ECU), which then calculates the steering assistance required and controls the servomotor.

Why supply an entire EPS chipset? The goal was to provide all the necessary semiconductor components for an electric power steering system and fine-tune them in a way that leads to a high level of availability and enables fail-operational or fail-safe operation. Correspondingly, coordinated components offer reliable interoperability and integrated compatibility. An important aspect was to guarantee functional safety - for this, all the relevant components not only have to meet the highest automotive quality standards, but also have to be designed according to ISO 26262.

EPS demonstrator

Infineon has developed a demo board with chipset components and a mechanical demonstrator. The demo board controls a 6-phase electric motor. Figure 1 shows the demonstrator set-up and Figure 2 the demo board with all the chipset components. They include the power supply chips (Optireg PMIC, TLF35584), 3-phase half-bridge drivers (TLE9183QK), 32-bit micro-controllers (TC23x with 200 MHz and 2 MB Flash), torque sensors (TLE4998C8D), motor position sensors (TLE5309D) and angle sensors (TLE5014D), Mosfets (in the SS08 package), and the CAN FD transceivers (TLE9251VLE, TLE9252VLC).

All components used are well matched and designed for high functional safety, energy efficiency, and integration density. For example, the safety power supply is predestined for EPS systems and offers corresponding monitoring and protection functions for Asil (automotive safety integrity level) D functionality, which is also supported by the bridge driver. All sensors are designed for systems according to ISO 26262 and offer very high measuring accuracy. The powerful micro-controller from the Aurix family can be selected for performance, flash capacity, timer architecture, and peripherals. In addition, the MCU has an integrated safety/security concept with ISO 26262 support, hardware redundancy and hardware security (HSM ▷

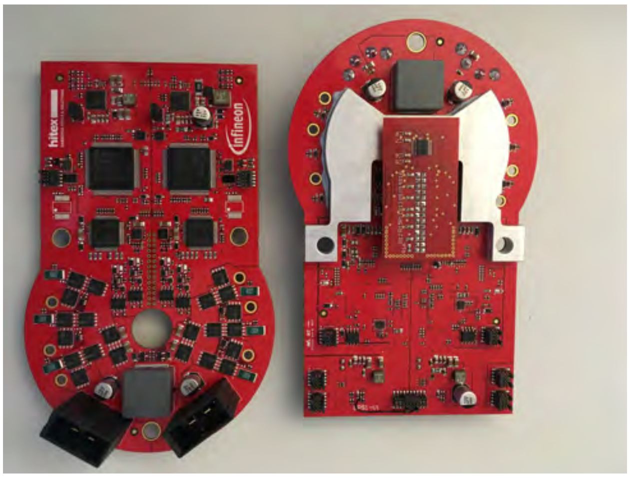


Figure 2: Compact demo board with EPS chipset (Source: Infineon)

module). Finally, the Mosfets offer very low on-resistance (RDS (ON) of 0,9 mΩ at 40 V) and excellent switching performance in rugged packages (SS08 or sTOLL).

The demonstrator architecture is a 6-phase system with two independent, isolated 3-phase subsystems for the required redundancy (Figure 3). Therefore, the dual sensors, power supply chips, micro-controllers, half-bridge drivers, and Mosfet half bridges can be powered by two independent batteries for a fail-operational system. Both subsystems run independently of each other. Each of them contributes half the torque to the entire EPS system. In the case of a fault and thus a failure of one subsystem, the other would take over the EPS functionality on a proportionate basis.

Precision sensors

In order to ensure high functional safety in cars, a system partitioning with redundancy and efficient, reliable sensors are required. This is the only way to ensure a high level of availability, thereby enabling the system to remain fully functional in the event of a component failure. Therefore, sensors in electric power steering systems must not only be very precise, but also ensure functional safety. The sensors used here can be applied in ISO 26262 systems. Infineon's answer to the demand for sensor redundancy is integrating two sensors in a dual-sensor package (Figure 4).

The linear Hall sensor TLE4998C8D ensures accurate detection of the torque or steering moment. It very precisely scans the linear or angular position and digitally compensates temperature and mechanical stress, which ensures excellent stability over the entire temperature range and lifetime. The TLE4998C8D integrates two independently programmable linear Hall sensor ICs with SPC (Short PWM Code) protocol. The protocol allows the measured data to be transmitted initiated by the control unit. For flexible use, customers can choose between different interfaces (Sent, SPC, PWM only as single-chip).

The TLE5014D angle sensor is also a dual-chip version. This allows easy implementation of the required redundancy in system design. The sensor works extremely precise over the entire temperature profile and lifetime, making it ideal for use in power steering applications. The sensors are preconfigured with respect to the settings and precalibrated with respect to the temperature. As a result, customers can easily implement them. Again, customers can choose between different interfaces (Sent, SPC, SPI and PWM).

The dual-sensor chip TLE5309D combines an AMR and a GMR sensor with diagnostic functions in one package. The dual GMR/AMR angle sensors are used for analog angular position detection in safety-critical motor applications. The TLE5309D combines the very high accuracy of the AMR sensor with the wide measuring range of 360 degrees of the GMR sensor. Thanks to a short propagation delay (less than 9 µs) the sensor is prepared to meet highest requirements regarding speed and accuracy in electric motors and electric power steering systems. In addition, the sensor also offers a quick start of less than 70 µs and a low total power consumption.

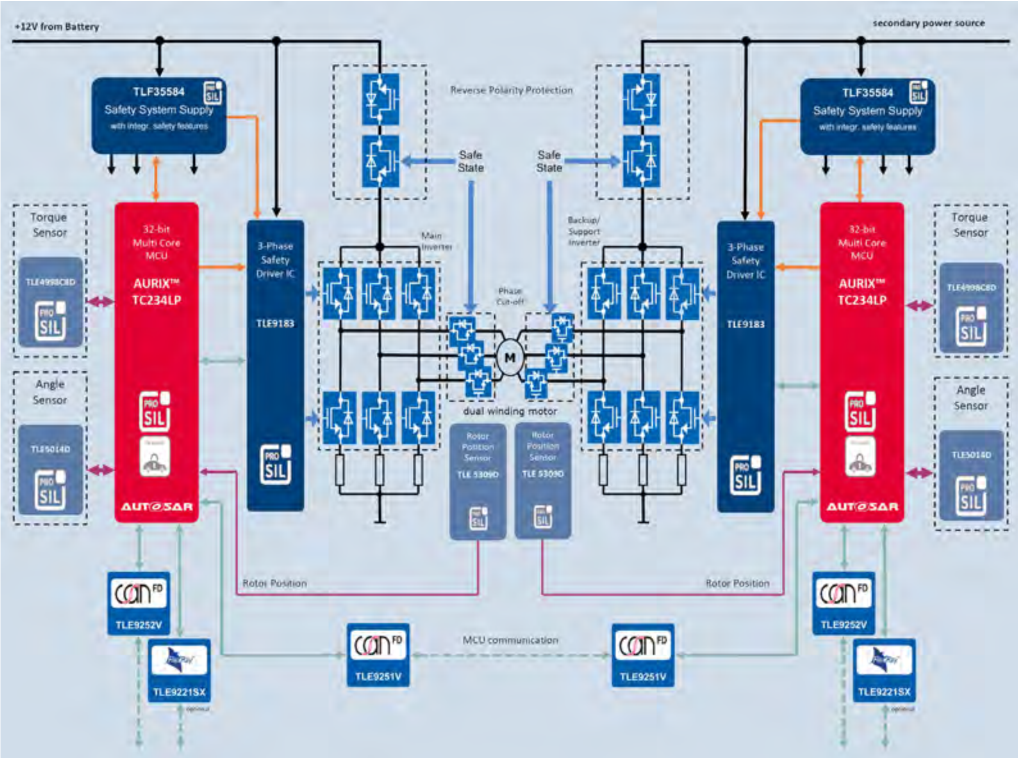


Figure 3: Block diagram of the redundant demonstrator architecture based on the EPS chipset (Source: Infineon)

Power supply and half-bridge driver

Safety-relevant systems also require a monitored voltage supply to ensure the functionality of the system components. The power supply and monitoring device TLF35584 (Figure 5) supports ECU designs in the context of ISO 26262 up to Asil D. The relevant main monitoring functions of the TLF35584 are undervoltage/overvoltage monitoring of the generated supply voltages, external watchdog monitoring of the micro-controller and external monitoring of the safety management unit of the Aurix MCU. Integrated monitoring of the status of these monitoring functions is made possible by a micro-controller-independent shutdown path for the system via the "safe state" outputs. Voltage monitoring is supported by a self-test (Bist).

The TLF35584 provides voltage to the controller through separate controller outputs with a monitored voltage for the micro-controller (3,3 V or 5,0 V, selectable), its analog-to-digital converter (ADC), standby controller, multiple transceivers, and sensors. For sensors, two independent tracker outputs are available, which are essential for setting up the safety-relevant sensor systems. The voltage regulation is based on an architecture with a DC/DC pre-regulator and linear post-regulator. To support cold-start-relevant systems, the TLF35584 offers an optional boost converter for input voltage stabilization and functional range expansion up to a battery voltage of 3 V.

The TLE9183QK 3-phase half-bridge driver IC has also been developed according to ISO26262. It has extensive protection and monitoring features, including limp home functionality. The power cycle can be adjusted from 0 % to 100 % without restrictions. Other features include three current sensor amplifiers, a low quiescent current operating mode, and a phase voltage feedback function with SPI (serial peripheral interface) programmable thresholds.

Safety micro-controllers

The 32-bit multicore micro-controllers from the Aurix family are tailored to the needs of powertrains as well as automotive safety applications. The family is highly scalable (single, dual or triple core, 80 MHz to 300 MHz, 0,5 MiB ▷

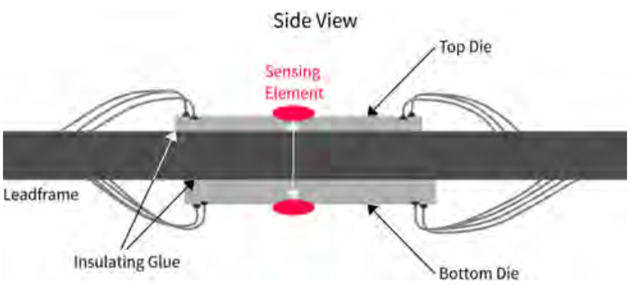


Figure 4: Dual-die sensors such as the TLE4998C3D, TLE5014D, and TLE5309D facilitate simple and efficient redundancy implementation (Source: Infineon)

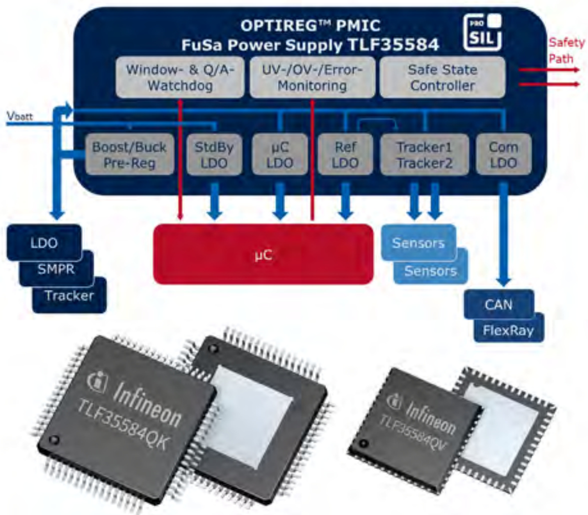


Figure 5: The TLF35584QK/QV safety power supply optimized for the Aurix micro-controller and sensors is ideal for EPS applications (Source: Infineon)

to 8 MiB flash memory, etc.) and is available in numerous package options. With high real-time capability and integrated safety/security features, the Aurix family is the ideal platform for a wide range of automotive applications. This includes engine control units, gearbox controls and controls for electric and hybrid vehicles, as well as suspension systems, brake systems, electric power steering systems, airbags, and driver assistance systems.

The Aurix architecture was developed following an ISO26262-compliant process. It is designed so that Asil D security requirements can be implemented in a very efficient manner. The micro-controllers combine a powerful multicore architecture along with specialized security technologies such as secure internal communication buses and a distributed memory protection system. Special protection mechanisms allow the integration of software from different application areas, allowing multiple applications and operating systems to run smoothly on the Aurix platform, even with different Asil ratings. In addition, a hardware security module (HSM) is integrated for high protection against manipulation.

Outlook

The complete Infineon EPS chipset will be available from mid-2019. In addition, in a subsequent step, increased performance, integration density (more functions and a reduced package size) and further improvement of the EMC robustness are planned. This means that even more powerful components with a new micro-controller (new generation of Aurix micro-controllers), power supply ICs, half-bridge drivers ,and sensors will be available for the upcoming EPS chipset generation.

With regard to future stages of automation (level 3 and higher), the demands on electric steering will also increase. Steering systems without the mechanical coupling between the steering wheel and the steering gear used to date are expected in the market. These steer-by-wire concepts require even higher availability and reliability. Infineon's EPS chipset also refers to these future applications, enabling future-proof steering system designs. ◀

Authors


Goran Keser, Christoph Unterreiner
Infineon Technologies
support@infineon.com
www.infineon.com

Galvanic isolated CAN FD repeater reference design

Texas Instruments has published an application note describing a two-port repeater using the company's CAN transceivers and an arbitration-logic.

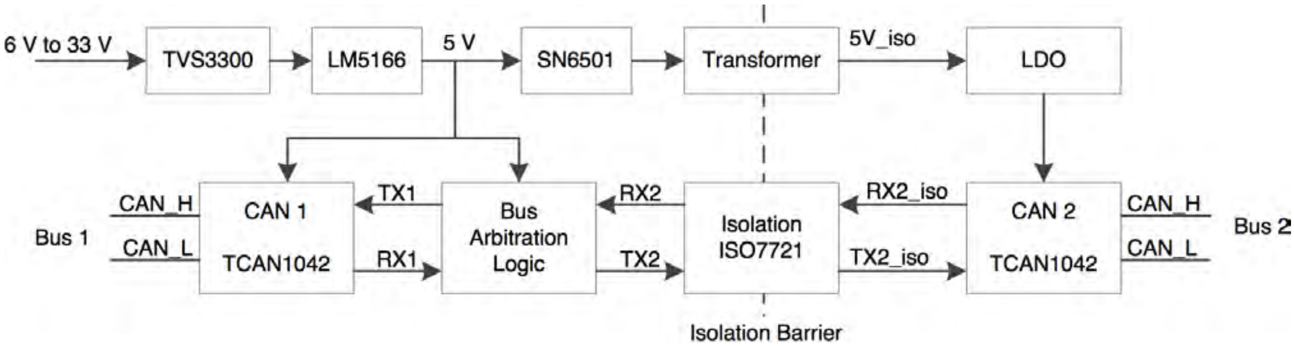


Figure 1: Block diagram of the isolated CAN FD repeater (Source: Texas Instruments)

This isolated CAN FD repeater reference design adds electrical isolation between two bus segments. The CAN FD frames on either bus segment side are repeated to the other side. The transceiver and arbitration logic in this reference design support bit rates up to 2 Mbit/s. The design is supplied by a wide range voltage supply between 5 V_{DC} to 33 V_{DC} and protected from high-power transients or lightning strikes by a flat-clamp surge protection device.

Adding bus isolation inside the CAN FD device protects against dangerous electrical transients and eliminates ground loops. When there is no internal isolation, then the device is exposed to some electrical challenges. However, isolation still can be added between non-isolated CAN FD devices by adding an isolated CAN FD repeater into the bus lines.

The proposed CAN FD repeater design consists of two TCAN 1042H transceivers. Between these two transceivers is an isolation barrier and an arbitration logic. The arbitration logic detects which of the two transceivers enter the dominant state first and prevents the loopback of the secondary transceiver side, which would stall the CAN FD network into dominant state otherwise.

Arbitration logic

The arbitration logic is needed to prevent both CAN FD networks to get stuck in dominant state due to the loopback function inside the CAN FD transceivers.

The arbitration logic detects, which of the two CAN FD ports is entering the dominant state first. Based on the detection of the first CAN FD side, the arbitration logic blocks the secondary CAN FD side from also asserting dominant state due to the loopback. Once the first CAN FD segment releases the dominant state the arbitration logic ▷

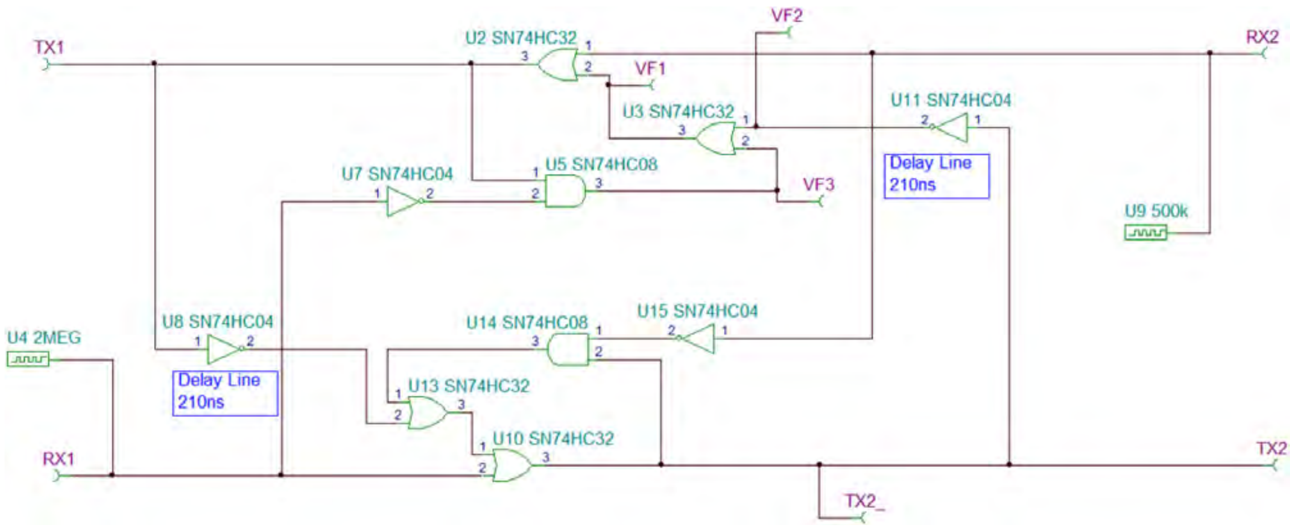
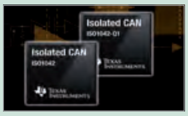


Figure 2: CAN FD arbitration logic circuit (Source: Texas Instruments)

CAN Newsletter Online: CAN FD transceiver



Electronica 2018

Transceivers with CAN FD and 70-V bus-fault protection

Texas Instruments (TI) has introduced two more CAN transceivers. They offer ±70-V_{DC} bus-fault protection and ±30-V common-mode voltage range.

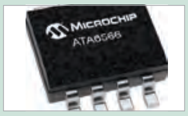
Read on

System Basis Chips

With CAN FD support

I nfineon Technologies is launching two System Basis Chip (SBC) families: Lite and Mid-Range+. They are compliant with ISO 11898-2:2016 and qualified for 5 Mbit/s.

Read on



CAN FD transceivers

Compliant to ISO 11898-2:2016

Microchip offers a series of transceiver chips, which are qualified for 5 Mbit/s respectively 2 Mbit/s. Some products support stand-by functionality.

Read on

5-Mbit/s CAN FD chip

Stand-alone controller with on-chip transceiver

Texas Instruments (TI) has launched the TCAN 4550 stand-alone CAN FD protocol controller. On-chip is also a 5-Mbit/s qualified transceiver.

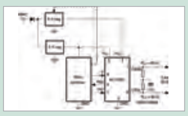
Read on

CAN FD transceiver

Features 5 Mbit/s

Infineon (Germany) has released the CAN FD TLE925x transceiver family. They comply with ISO 11898-2:2016.

Read on



CAN FD transceiver

Supports data rates up to 5 Mbit/s

ON Semiconductors has launched the NCV7351F transceiver, which complies with ISO 11898-2:2016. It is qualified for bit-rates up to 5 Mbit/s.

Read on

CAN FD transceiver

Bit-rates up to 2 Mbit/s and higher

Several chipmakers have qualified CAN high-speed transceivers for data-rates up to 2 Mbit/s. Transceiver supporting higher speeds (4 Mbit/s or 5 Mbit/s) are under development or have been pre-announced.

Read on

Embedded World 2018

Evaluation board with CAN FD transceiver

Microchip offers development boards for its ARM-based MCUs featuring CAN FD connectivity. The products are equipped with the company's CAN transceivers qualified for 5 Mbit/s.

Read on

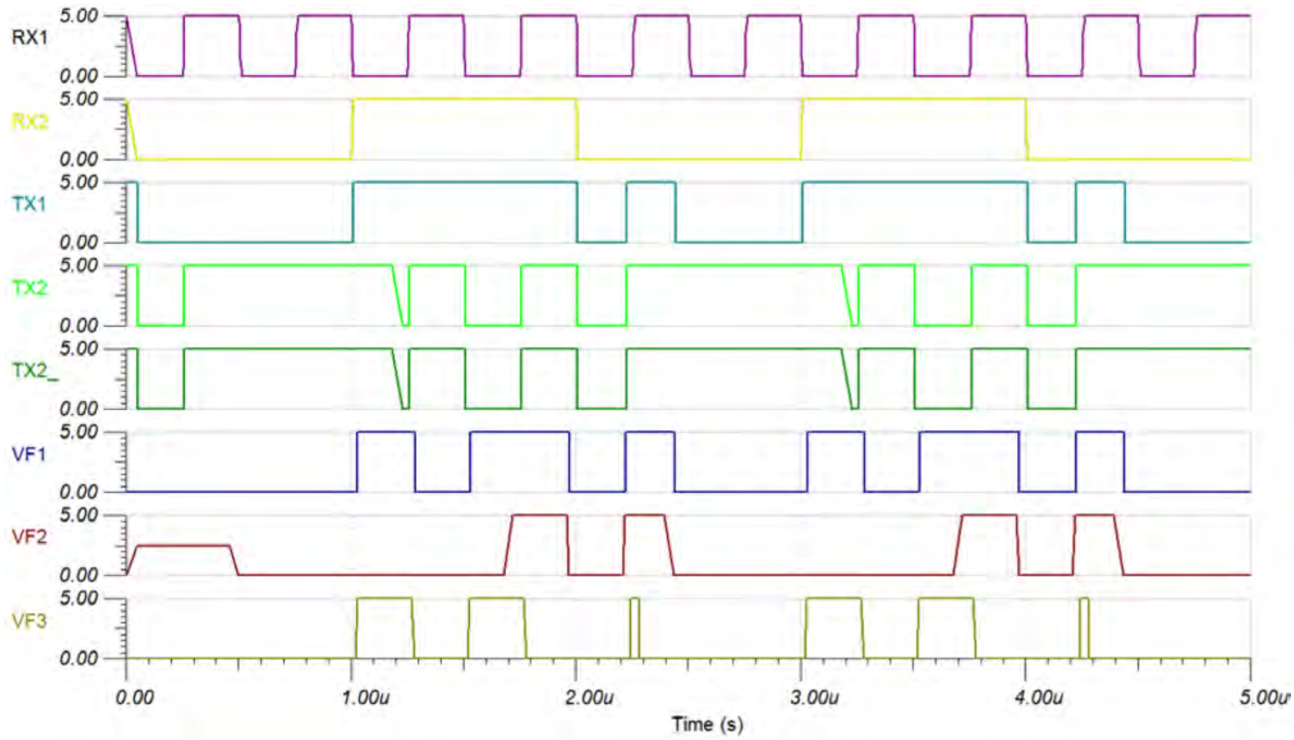


Figure 3: Arbitration logic simulation results (Source: Texas Instruments)

starts a time delay unit. After the time delay unit expires, the block of the secondary side is removed. The arbitration logic works in both directions.

The delay line unit has an asymmetric delay of the CAN FD line transition. This unit has a delay of 210 ns from dominant state to resistive state and no delay from resistive state to dominant state. The asymmetric delay of 210 ns is needed to support higher bit rates than 2 Mbit/s. Texas Instruments has simulated the arbitration logic. The simulation showed when both sides of the CAN FD interfaces get into a dominant state. Then the side that stays longer in the dominant state wins the bus arbitration, and the port that enters recessive state goes back to receive mode.

The stimulus on the left side is a 2-Mbit/s square wave signal and on the right side a slower 500-kHz square wave signal. Note that the stimulus is not CAN signal because they do not detect a dominant state and switch off driving the bus. The two stimuli are mainly used to test the initial arbitration of the arbitration logic. The secondary side (RX2) stays longer in the dominant state and therefore is in favor of the arbitration detection logic.

The capacitor is charged (VF4) during the transition from dominant state to resistive state (V_in). When the VF4 voltage reached the threshold, the time delay unit set V_out to recessive. As the time delay unit is asymmetric, there is no delay when V_in goes to dominant and V_out goes immediately dominant, too.

Galvanic isolation logic

Texas Instruments has chosen the ISO 7721 component for this reference design, because it supports two data lines, one in each direction. It isolates the two transceiver signals RX and TX between the two CAN FD segments. The component coming in an SOIC (D) package supports 3000 V of isolation. Note that if a higher isolation voltage is required, then the SOIC (DW) package must be used.

The chipmaker has tested the reference design. For the test two Beaglebone Black modules were used. They feature the TIDA-01406 compliant energy efficient and isolated CANopen interface. The test results are documented in [1].

hz

Based on TIDA-01487 [1].

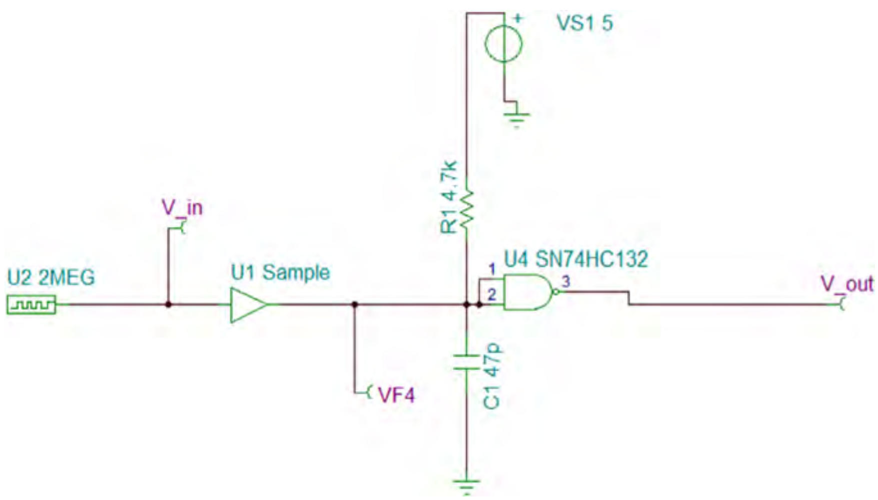


Figure 4: Delay logic circuit (Source: Texas Instruments)

References

[1] TIDA-01487: Isolated CAN FD Repeater Reference Design; Texas Instruments, 2018.

CANopen FD multi-level security demonstrator

Many CAN-based networks open multiple attack vectors for hackers, especially after they have gained access to the system either remotely through a gateway or even physically.

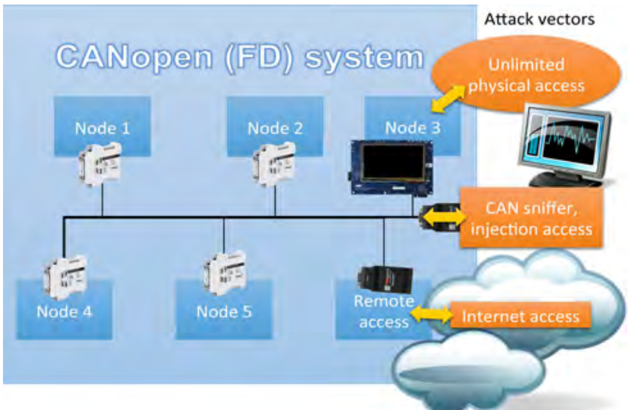


Figure 1: The CANopen (FD) attack vectors (Source: EmSA)

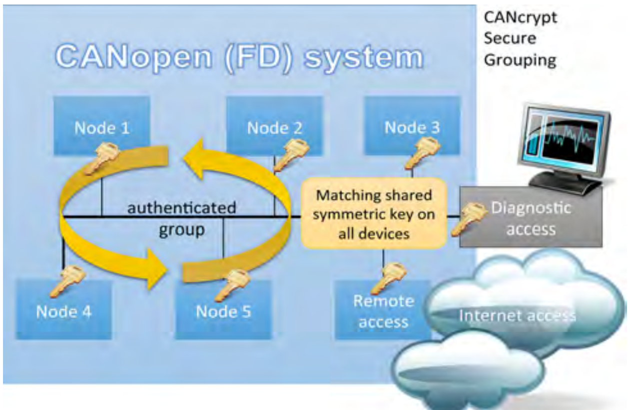


Figure 2: CANcrypt secure grouping based on a shared key (Source: EmSA)

The CANopen FD multi-level security demonstrator consists of a simple CANopen FD system with two generic I/O devices from Peak-System (buttons, signal lights) and a controller device with touch screen and text display (LED matrix). All of these are based on LPC54618 or LPC54S018 micro-controllers from NXP. An optional CANopen FD Bluetooth gateway can be used to provide a tablet remote access to the controller.

The different security levels implemented in the demonstrator protect from multiple attack levels:

- *Hardware level attack:* extract keys and/or codes from micro-controllers when unlimited physical access is available (through debug access or code extraction services).
- *Security solution:* Use micro-controllers with special protected non-volatile storage like the NXP LPC54Sxxx micro-controllers with PUF (physical unclonable functions) protection to protect code and keys.
- *CAN (FD) frame injection attack:* use a CAN sniffer connected to the system or a hijacked connected CAN (FD) device, listen to all CAN (FD) frames and inject fames to trigger control functions.
- *Security solution:* Use NXP TJA115x Secure CAN Transceiver (HW) or CANcrypt message monitoring (SW) to react to detected injections.
- *Advanced CAN (FD) frame injection attack:* perform CAN (FD) frame injections after the device monitoring these CAN IDs has been taken offline or from a hijacked, authorized device.
- *Security solution:* Use CANcrypt (FD) secure grouping with secure heartbeats and message authentication to prohibit injected, unauthorized messages from being accepted.
- *Remote access attack:* hijack a CAN (FD) device with Internet access. If that device is authorized and has the CANcrypt key available, authorized CAN messages might be generated.
- *Security solution:* Use end-to-end security with DTLS where the device providing Internet and CAN FD access does not have the keys required for the end-to-end protection.

Secure grouping with CANcrypt

CANcrypt is based on a shared key that is installed or generated at the end of the system integration process, after all components have been installed on the network. During operation a dynamic key based on that shared secret is used and continuously updated through a secure heartbeat mechanism. ▷

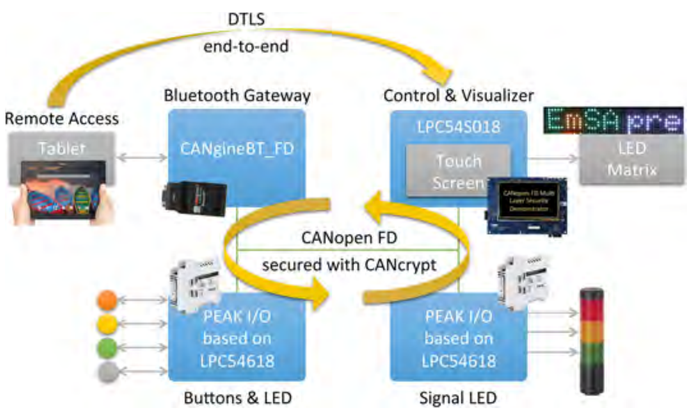


Figure 3: The CANopen (FD) multi-level security demonstrator (Source: EmSA)

End-to-end security for CANopen (FD) with DTLS

The wide-spread transport layer security (TLS) and datagram TLS (DTLS) protocols are the basis for secure Internet traffic, i.e. for secure online banking, e-commerce, or social media. Both protocols offer end-to-end (E2E) security with regard to:

- authentication using pre-shared keys or certificates,
- confidentiality using symmetric cryptography, where the keys are either pre-shared or negotiated with asymmetric cryptography,
- integrity using hash algorithms

Till today, industrial field busses are still lacking such security features. Now, developers from Embedded Systems Academy and researchers from Offenburg University of Applied Sciences demonstrate, how DTLS can be used to achieve Internet-grade protocol security in CANopen (FD) systems.

Using dedicated entries in the Object Dictionary of CANopen (FD) nodes, two nodes within the network (intradomain) or even one node within and one external node (interdomain) can establish a secure DTLS tunnel. Network intermediaries, not even CANopen (FD) gateway, need to be trusted.

Secure interdomain communication is particularly useful for remote service and configuration use cases, firmware updates, or highly security-critical transfers in general.

CANcrypt-secured messages have a security record embedded and can be encrypted if needed. Authentication is provided based on an encrypted CRC16 value. The security algorithms used are configurable. Default methods are XTEA64 or AES128.

CANopen FD multi-level security demonstrator

Figure 3 shows the functional elements of the demonstrator. All CANopen FD devices are protected with CANcrypt message monitoring and secure grouping.

A CANgineBT-FD module by ESSolutions provides an Android tablet wireless access to the CANopen FD network. DTLS end-to-end security is established between the tablet and the controller and visualizer module which accepts remote control commands and displays text strings received by the tablet.

The demonstrator is shown at the Embedded World 2019 in Nuremberg, hall 4A, booth 220. A video about the demonstrator will be released after the Embedded World. ◀

Author

Olaf Pfeiffer
EmSA (Embedded Systems Academy)
info@esacademy.com
www.esacademy.de

Decision support for functional safety encoders

If to use certified or non-certified functional safety products for safety-related applications is a hard question. In this article several technologies used in encoders are explained.

Figure 1: Application areas for the encoders are for example an aerial ladder (Source: Fraba)

Today, engineers have the choice of using certified or non-certified functional safety products for safety-related applications. This choice is not easy, and the task is likely to be influenced by considerations such as the availability of products, their cost, and the required integration effort. As well, the ability to react quickly to end-customer demands for machine adaptation can be critical to the final decision.

Fraba has extensive experience in the development of safety products. In 2009, the company introduced their first SIL3 / PLe-rated encoders with a CANopen Safety interface. This encoder was based a redundant design, with duplicate optical measurement systems. By comparing the output from these two systems, the device's primary micro-controller (MCU) could detect errors or component failure with a sufficient level of certainty to meet SIL3 requirements. This system was implemented with a pre-certified micro-controller running the CANopen Safety stack. A second small MCU provided a monitoring function. With two redundant measurement modules, these devices were slightly longer than the company's standard optical encoders and more expensive. However, these devices offered important advantages over the use of two standard encoders to achieve redundancy, eliminating the need for duplicated couplings, mounting brackets, and cables. SIL3-rated encoders were available in single or multi-turn versions.

More recently, Fraba developed a second generation of safety encoders as successor, designed to meet SIL2 / PLd requirements. These are based on magnetic measurement technology, which is less expensive than optical systems and better suited to harsh environmental conditions. They feature two redundant Hall sensors. These sensors measure the rotary position of a single magnet mounted on the encoder's shaft and mechanical gearing. There are several MCUs that carry out signal conditioning for the two position sensor channels and verify the position values read by the two channels. Both single-turn and multi-turn models are available with CANopen Safety interface and Profisafe interfaces. CANopen is widely used for mobile and construction machines while Profisafe is important for manufacturing automation.

A main advantage of the two encoders series described above is that they are easy to integrate into safety-critical systems. The engineer can "trust" these safety-certified devices and the position values that they produce, leaving users to focus on the remainder of the application task. On the other hand, this ease of use has the drawback of reduced flexibility when handling failure situations. These sensors simply transmit an error code and switch off when a measurement discrepancy is detected. Safety requirements are fulfilled, but availability is gone. Customer specific requests for adaption build into the hardware and software, requiring extra effort for implementation, testing and documentation, is leading to less flexibility.

Ten years of experience in this market has taught us that machine builders often face enormous price pressure, especially for high volume projects. There are also time-to-market pressures that require high flexibility. In response to these needs, Fraba has developed a product series of less expensive non-certified encoders that are also suitable of use in safety-related applications. The key concept here is to build devices that combine two different measurement technologies – optical and magnetic – in a single encoder package. These "redundant-diverse" encoders implicitly qualify for a safety level of PL d according to ISO13849. Unlike the SIL-certified devices described above, comparison and verification of the measurements from these two channels is here the responsibility of the PLC logic. Is this type of encoder suitable for safety applications requiring PLd levels of ▷

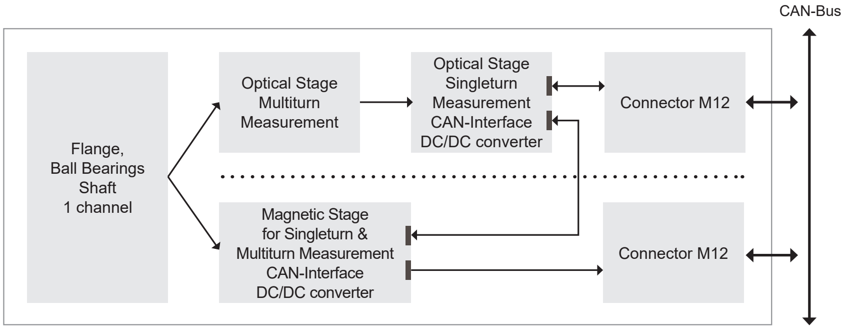


Figure 2: Block diagram of a redundant diverse encoder (Sourc: Fraba)

performance? The answer is yes, because these devices meet key performance/reliability requirements: MTTFd is high; CCF exceeds 65 points; and the overall architecture of the device meets Category 3 requirements. That means that on the PLC side a DC (diagnostic coverage) of "low" is adequate, reducing the implementation effort (e.g. to simple comparison of the two channels).

By defining of a suitable allowed deviation range between the two both position values, the engineer can optimize control system behavior to meet application requirements. In case of an obvious failure in one encoder channel, the PLC can change the machine operating mode from 'automatic' to 'with assistance' and continue to use the output of the functioning encoder channel, taking into account the fact that it is operating at a reduced level of trustworthiness. In the end, this means a higher availability than with a safety device that just turns off in the case of failure. For mobile machines like concrete pumps or aerial platforms, a level of high availability is an important requirement.

In summary, safety certified encoders are a good choice for customers using lower quantities, short development times, lower safety knowledge, and acceptance of higher product cost. However, for cases where high flexibility, series volumes, and price pressure are of prime importance, a non-certified redundant diverse encoder technology offers a lot of benefits. It's up to the customer to decide on the right technology for his application.

The Bauma 2019 exhibition takes place from 8 to 14 April in Munich, Germany. Fraba shows there its products in hall A2, stand 434.

Author

Klaus Matzker
Fraba
info@posital.de
www.posital.de

Take product quality to the next level

When it comes to load data acquisition, Jungheinrich relies on HBM. The QuantumX CX22B-W stand-alone data recorder plays a key role in this.

Figure 1: Data recorder and universal amplifier in the EJE series of electric walkie pallet trucks (Source: HBM/Jungheinrich)

Jungheinrich is a manufacturer of forklift, warehouse, and material flow technology. Recently the German company joined the CiA association. The company provides warehouse logistics solutions offering high functionality, reliability, and quality. These are the result of extensive testing prior to and also after the market launch of new products. Jungheinrich relies on extensive product testing at the customers' premises. The insights about actual loads in day-to-day operation gained under real conditions are not only used to validate the values forecast during product development, the specialists also use the practical test results to continuously improve their products.

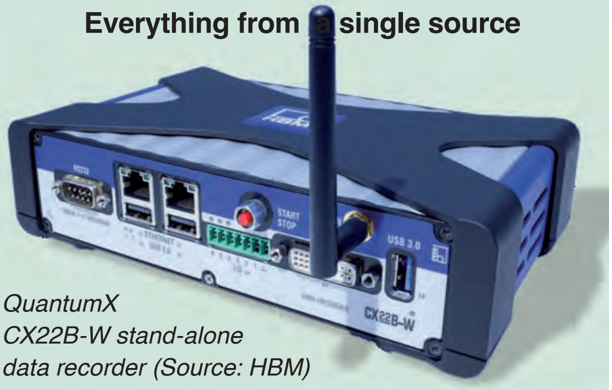
For measurement and analysis, Jungheinrich relies on solutions from HBM such as the universal QuantumX data acquisition system. The EJE series of electric pedestrian pallet trucks from Jungheinrich allows customers to load and unload trucks and to transport pallets over short distances. The pallet trucks feature a maintenance free three-phase AC motor. Furthermore, the EJE 116 to 120 pedestrian trucks, regardless of their compact dimensions, offer a striking capacity of up to 2 t.

The EJE series' performance data is, amongst other things, a result of the fork lift trucks' quality and continuous optimization. This is why the company performs extensive series of tests, not only during development. As part of their quality assurance and further development program, the pallet truck provider collects valuable data directly on site at select customers - upon consultation with the customer and in compliance with applicable data protection guidelines. The company acquires the required data on the actual device structure in practical use and virtually "undercover" - without any effort to the user or loss of performance. The measurement electronics, invisibly integrated in the pallet truck, autonomously takes the required measurements in day-to-day use.

The QuantumX CX22B-W stand-alone data recorder is the heart of the test and measuring equipment used in this "undercover operation". The compact measurement modules are distributed and invisibly integrated behind the pallet truck cover. The data recorder stores the test data that is either supplied by strain gauges, pressure transducers, current, voltage, acceleration, and temperature sensors or taken from the in-vehicle CAN network directly in the data recorder. Neither connection to a PC nor user intervention is required - the system operates autonomously in the background.

After about two weeks regular day-to-day use, the real-life data is read out on site at the customer's premises. The goal for the future is to implement this via remote access (cellular network) to further reduce personnel requirements. The data packages are subsequently analyzed using nCode Glyphworks software from HBM, a tool for test data analysis in engineering with a focus on durability and fatigue life analysis. The analysis results allow valuable conclusions to be drawn about how loads ▷

Everything from a single source

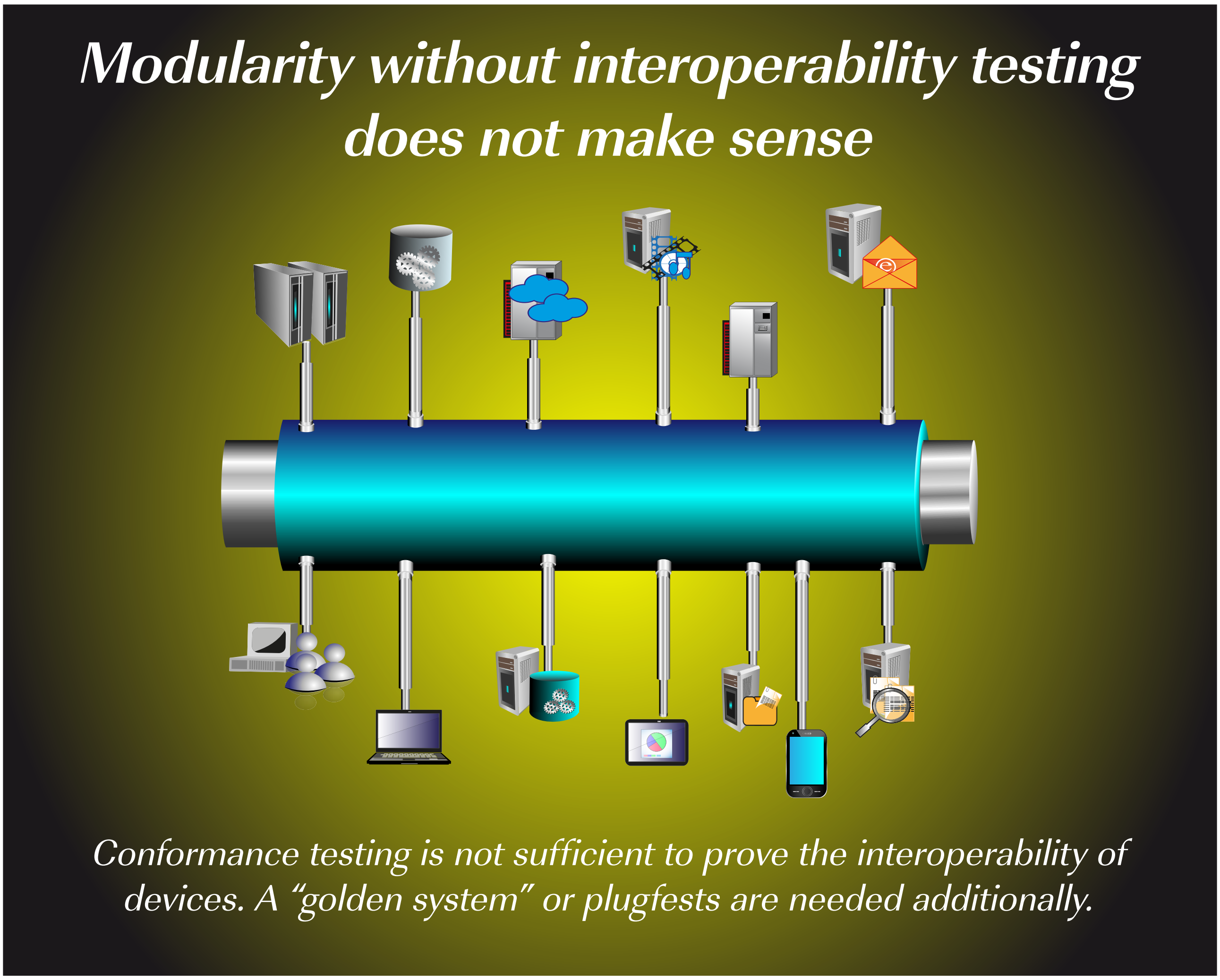


QuantumX CX22B-W stand-alone data recorder (Source: HBM)

Jungheinrich has been using reliable test and measurement equipment from HBM for several years now. On the one hand, this is due to straightforward collaboration and fast response to inquiries. On the other hand, HBM provides everything from a single source, complete solutions for the entire measurement chain as well as components offering universal use, scaling, and convenient configuration. Moreover, HBM test and measuring equipment is outstanding for its reliability and high performance. One example of this is the QuantumX data acquisition system used in field testing of EJE type series electric pedestrian pallet trucks: It provides compatibility with the Jungheinrich CANopen network and, in addition, fast disassembly, high sample rates and up to 512-GiB memory capacity. Wireless routers can easily be connected via Ethernet at any time.

affect the structure of a product in practical use. Both the values forecast within the scope of simulations in the development stage and the values determined in the test bench can thus be validated on the basis of actual data acquired in practical use. In addition, the insights gained under real-life conditions provide a basis for the further improvement of products from Jungheinrich. ◀

Based on information by HBM and Jungheinrich



(Source: AdobeStock)

Increasingly, network system designers need to develop systems, which are highly configurable. In extreme, each system is unique. Modularization is the solution. Of course, to reduce the development effort, the module interfaces should be standardized. This can be done proprietarily or openly meaning that official standardization bodies such as ISO and IEC or industry associations such as CiA or SAE release such interface specifications.

In case of open network approaches, system designers demand increasingly conformance tested products. This is why in the automotive industry CAN conformance testing on the chip level is on the agenda since many years. Nearly all CAN protocol controllers used by automakers are conformance tested. Since the beginning, Bosch provided such a test tool to the CAN chipmakers. In the meantime, there are two CAN conformance test plans internationally standardized: ISO 16845-1 for the CAN data link layer and ISO 16845-2 for the CAN transceivers including those with low-power mode and selective wake-up capability. Typically, those conformance test systems are based on the conformance testing methodology and framework as standardized in the ISO 9646 series.

Conformance testing is also a topic for CAN-based higher-layer protocols such as CANopen. CiA provide since many years, a CANopen conformance test tool, which implements the CANopen test plan as specified in CiA 310-1. The CiA office uses this tool for conformance testing. The CANopen conformance testing is not mandatory. Unfortunately, there are some devices on the market claiming CANopen conformity, but they just may contain traces of PDOs and SDOs. Those products make the system designers unhappy. Lessons have been learnt: For CANopen FD devices conformance testing at CiA office is obligatory.

For the SAE J1939 protocols no conformance test plans exist. The J1939-based Isobus network standardized in the ISO 11783 series provides conformance test plans developed by the nonprofit AEF association. All Isobus-labeled electronic control units (ECU) must be conformance tested by one of the authorized test houses.

Conformance testing is like spellchecking in human communication. It just tests the behavior of one single ▷

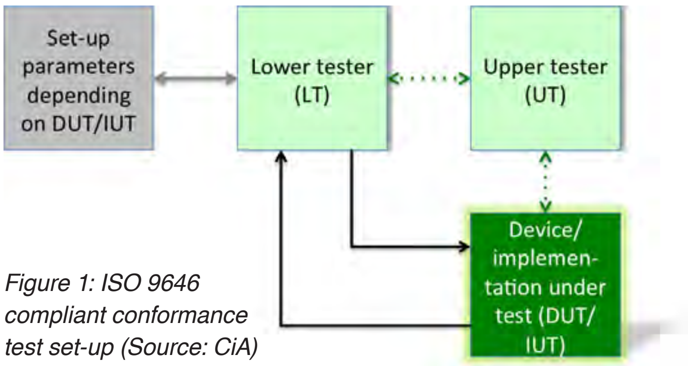


Figure 1: ISO 9646 compliant conformance test set-up (Source: CiA)

Figure 2: Impression from the Isobus plugfest in Bologna (Source: AEF)

device. The device-under-test (DUT) is justified that its communication interface complies with the conformance test plan. Normally, the test set-up comprises the DUT and the lower tester (LT) generating test pattern and evaluating the response on the bus-lines. If also the interface to the higher-layers is tested, an upper tester (UT) is needed. The LT and the UT are linked by means of an interface, in order to evaluate the reaction on the test pattern on the upper interface. As said, conformance testing does not prove the interoperability between devices. This is the same as in human communication: Spellchecking does not guarantee that the reader interprets correctly your text; it just demonstrates that you have not violated grammar rules and that the words are well spelled.

Interoperability this is, what the system designers are interested in. Of course, conformance testing improves the probability of interoperability, but does guarantee it. There are two options to test interoperability. The "golden system" is a reference network system, to which you connect the DUT and test, if it communicates with others and does not disturb the communication between them. The second approach is a plugfest. Plugfests are test events, in which module suppliers connect their devices to those of other manufacturers. CiA has organized, for example, several plugfests for CAN FD implementations. The AEF association arranges twice a year plugfests for Isobus-compliant ECUs. The next one is scheduled in Lincoln (Nebraska) for May and the following is planned in France in September. CiA also put on bi-annually plugfests for CANopen Lift devices. In March, the next one will take place in Nuremberg (Germany). CiA organizes also generic CANopen plugfests on demand of interested parties. Later on this year, CiA plans to schedule a CANopen FD plugfest.

Interoperability tests for the next generation CAN protocol, CAN XL, will be arranged, when first implementations are available. CAN XL with payloads up to 2048 byte is specified by a CiA Special Interest Group (SIG). Volkswagen initiated the protocol development. Intended applications are small radars, advanced driver assistance systems, and eCall for volume cars. ◀

Author

Holger Zeltwanger
CAN Newsletter
pr@can-cia.org
www.can-newsletter.org

Anniversary: Measurement in drives and mobile machines

Figure 1: Speed and length measurement directly in the tool (Source: Wachendorff)

For 40 years, Wachendorff has been offering CAN-based sensors and automation products for mobile machines and municipal vehicles. Here's a little time travel.

In the beginning, the company offered small and robust speed displays in vertical drilling machines as well as temperature displays in asphalt machines. For about 25 years, Wachendorff has also supplied incremental encoders as sensors for outdoor applications. Initially, they were used as speed sensors, consisting of a rotary encoder with a measuring wheel, as well as a robust mounting device, which produced the necessary contact pressure on the conveyor belts in quarries. Other applications included speed and position sensors on construction hoists, or speed sensors on wind turbines, often mounted on the slip ring.

Just over ten years ago, the company developed a series of absolute encoders that offer enormous advantages, not only over conventional encoders, but also over conventional sensors, such as potentiometers or simple angle sensors. These enhancements make the products ideal for use in outdoor applications, or in environments with high mechanical demands (e.g., in mobile work machines, or even in aircraft elevators).

Figure 2: Encoder used in harbor cranes (Source: Wachendorff)

These absolute encoders feature single-turn Quattromag technology, which uses four Hall sensors and can measure angular position more accurately and more quickly than conventional sensors using a diametrically split magnet mounted on the face of the encoder shaft. With a patented calculation algorithm, interferences are eliminated. This gives the processing electronics much better signal quality with less noise. In addition, these multi-turn encoders are equipped with Endra technology; a technology that is able to count and store revolutions via a Wigand sensor, even when de-energized. Here too, a patented process enables precise and reliable signal processing.

In combination, these two technologies are almost unbeatable for mobile applications: Because it's contactless and enclosed in housing, it's wear-free, – and also has no moving parts such as gears; this paired with the fact that it doesn't have a battery makes it completely maintenance-free. The encoders work reliably and are temperature-resistant in ice or in the desert. They are also available in an off-shore version.

Another not to be underestimated advantage is the compactness (36-mm housing) and the low weight combined with high bearing loads and rugged protection classes such as the IP65, IP67, and up to IP69K. Wachendorff integrated the usual CAN interfaces compactly on one board (CANopen, CAN proprietary, CANopen Lift, and J1939). The applications have become very diverse. In combination with a pulley system, absolute encoders can be used for measuring the travel ▷

Figure 3: This encoder is suitable for optimal metering of grit (Source: Wachendorff)

of a boom or the reach of a truck crane arm; without a cable system – directly on the winch – they can be used for length measurement. Other applications include angle measurement in wind turbines, mounted on the gear ring or directly in the cam switch, and also the feed measurement on vertical drilling machines, as well as the measurement of steering information such as angle and speed on the wheels of automated guided vehicles (AGVS) or heavy transporters. Angle measurement on cranes is a special application, as two encoders can be used here for redundant information, or the measurement can be supplemented further with a proximity switch. Whether for off-shore or on-shore applications, customers can rely on stainless steel housing that has been tested for salt water resistance.

All applications have one thing in common: the properties mentioned above are important selection criteria for the company's customers. In many cases, Wachendorff has supplemented additional CAN protocol properties or implemented minimalist protocols so that the connection to the respective controller can be implemented as simply as possible. With CANopen Lift, Wachendorff was able to put together a standard in the elevator industry with some control manufacturers, which makes it easier to design and automate elevators.

More and more reliable and robust encoders from the company will be needed to ensure the safety and control of mobile machinery, municipal vehicles, and all other outdoor applications. With mechanical and electronic variants Wachendorff ensures that the sensor not only solves its task in the application, but can also be quickly integrated into existing designs; for this, they send Step files and advises customers on-site or over the phone with the experience of more than 2500 customized solutions that are in use worldwide. The company also ensures that the encoder is easy to assemble and arrives logistically sensible to the customer. Worldwide and always with a 5-year warranty. ◀

Author

Robert Wachendorff
Wachendorff Automation
wdg@wachendorff.com
www.wachendorff-automation.com