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- 10/100 BaseT ETHERNET-CAN Gateway
- Electrically isolated
- Configuration and Diagnostics by webbrowser

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- CAN-USB interface
- Intelligent CAN interface with ARM 7
- USB 2.0 with high speed data rates of 480 Mbit/s
- Electrically isolated
- Provides high resolution hardware timestamp

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- PROFINET-CAN
- PROFIBUS-CAN
- PROFIBUS-DeviceNet
- EtherNet/S7-CAN

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- CANrepro: Replay of pre-recorded CAN message frames
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Mechanical assistants with embedded CAN networks

For farmers the day usually starts at 3 or 4 o'clock in the morning. They have to look after their cattle, feeding and milking them. Until now: Thanks to a milking robot, the cows milk and feed themselves.

This means a more comfortable life for farmers. They are able to go back to bed on a rainy day or can do other things such as cocking dinner or manage other tasks, because the cows now decide when it's milking time. Machines don't complain about getting up early. The robots feed and milk the cows without the help of a human, no one has to move the cows into the milking box. The animals go there on their own because they know there is food in the form of a measured amount of grain in the box.

Robotics in agriculture

Service robots are revolutionizing the agricultural sector. They sew, weed, fertilize, and feed animals with increasing autonomy. Netherlands-based company Lely, a leading manufacturer of robot milking systems, offers an entire line of products, from stall cleaning systems to automatic feeding systems, amongst them the CAN-featuring Lely Astronaut A4 milking robot for about $250 000 including a mechanical arm and teat-cleaning equipment. According to Lely, an increase in labor productivity is desired to ensure a healthy dairy business in the future. Achieving more liters of milk per worker in an animal-friendly way is what the company is aiming for. They think only one man can milk two million liters per year. On conventional dairy farms where milking is done twice a day now, production increases of 10 % to 15 % can be realized by means of their milking robot. It can handle about 180 milkings a day.

A robotic milking system offers the most reliable employee imaginable. This robot employee is there to milk for the owner 24/7 for years to come. It is trained to prepare the cow for milking, to attach the teat cups and to reattach them if required, to detach after milking, and to carry out post-treatment. Due to the robotic milking system, many factors can be monitored for each individual cow, factors that cannot be provided in a conventionally milked herd. With robot milking decisions are transferred from the farmer to the cow. It is all about early signals. Owners can treat their cows individually again, which results in improved health of the cows, shorter calving intervals, and reduction of feed costs.

In the so-called cow traffic, the cow decides when she wants to eat, get milked or lie down, thereby improving the well-being of the cow. This influences the cow's behavior when it comes to visiting the robot. Robotic milking is different from conventional milking in many ways. One of the main differences is that cows can be milked more in tune with their natural behavior. A main feature of the Astronaut A4 cow box is the walkthrough design called the I-flow concept. Because of it the cow walks straight in and out of the unit without making turns. This makes the process easier for the cow, which shortens the learning curve, increases the throughput, and as a result the capacity of the robot. Lyndon Williams, a farmer from Wales UK, said: "There was one cow we always needed to bring to the robot. But now – with the more open entrance of the Astronaut A4 robot – even this cow regularly visits voluntarily. She even comes too often!"

The robot arm remains underneath the cow and controls the entire milking process. With almost all sensors housed in the arm, measurement is done close to the udder and is therefore more accurate. Attachment speed and accuracy is a crucial factor for the capacity of the robot. When a cow goes into the box, the stainless-steel robotic arm moves under the cow, scans it with lasers to find the teats, and attaches four teat cups. The teat detection system (TDS) of the company features a three-level scanning technology, which provides detection of the teats. Above the cow is a mounted video camera that measures the animal's position, which means if the cow moves, the robotic arm moves with her.

The MQC (Milk Quality Control) is a tool for measuring milk quality. It is located inside the arm of the robot just beside the udder. During milking, the milk is continuously monitored per quarter. This provides the user with vital information on mastitis, fat and protein, and lactose for managing ▷

Figure 1: A farm may be the last place someone would expect to find a robot but actually, they have long been used to milk cows

Additional information

- Dr. Makota Mizukawa, Shibaura Institute of Technology, "RTC-CANopen", CAN Newsletter Print, June 2010
- Holger Zeltwanger, CAN in Automation, "Service robots need smart grippers", CAN Newsletter Print, September 2011
- CAN in Automation e. V., CiA 318 Draft Standard Proposal, "CANopen – Integration to RTC environments", February 2012
- CAN in Automation e. V., CiA 460 Draft Standard Proposal, "CANopen – Service robot controller profile", February 2012

> *"We use standard CAN components with a CANopen protocol.*
> *Peter Meyer*

milk quality and the cow's health. Mastitis is the inflammation of breast tissue. To prevent it, the optional MQC-C somatic cell count measurement system monitors the SCC per milking per cow. Alarming deviations are noticed and reported. The Milk Quality Control - Somatic Cell Count Indicator (MQC-C) is an optional part of the milking robot and is used to measure the class of the somatic cell count per cow per quarter. This is done in an automated process and can be set in Lely's management system called T4C (time for cows) to carry out the test per cow, group of cows, or the whole herd. The test is based on the drain time of a mixture of the milk and Astri-Cell (a fluid needed for measuring the somatic cell count in the milk). The test also indicates the udder health. The MQC-C gets its input (when to test) from the MQC and sends its output (test results, number of visitations) to the MQC. Results and class attentions of the test can be found in the T4C software. Hardware-related alarm messages can be found on the X-Link. The visitation lists generated by T4C can be found on the X-Link. The MQC-C can be built into the Astronaut A3 ex-factory but also installed on an existing Astronaut A3 milking robot. Depending on the production date, it is possible some other modifications must be done to install the MQC-C on existing milking robots. It has three primary parts: the sampler, the processor and the wall socket.

The sampler is installed on the support between the MQC and the milk jar. The function of the sampler is to separate a small quantity of the milk for the test when a test must be done. The sampler gets input from the processor and sends output to it. The processor is a box (a base and a cover) with pumps, valves, chambers and electronics. It is installed on the milking robot frame behind the intermediate panel and is attached to the processor installation bracket. The processor has three main functions: to transport, mix, test, and drain the mixture. The processor pumps the milk from the sampler to the processor and adds Astri-Cell to the milk. When the test is done, the processor pumps the mixture to the sewer. The processor gets its input from the sampler (electronic and milk samples), the wall socket (Astri-Cell, water and compressed air), and the MQC (via the CAN connector). The processor sends output to the sampler and the MQC. The wall socket is installed behind the intermediate panel on the right side of the machine room above the pumps. The wall socket joins the input of the water, Astri-Cell, and compressed air supply with the tube bundle that leads to the processor. It is provided with pressure reducers for the water and the air supply.

The CAN network of the milking robot supplies the electrical power to the MQC-C. According to Mr. Peter Meyer, Product Manager Dairy at Lely, they use standard CAN network components with a CANopen protocol, the internationally standardized (EN 50325-4) CAN-based higher-layer protocol for embedded control system. The CAN components of the robot are well supplied with 27,2 V_{DC} / 4 mA to 20 mA. The CAN network works via a two-wire connection (CAN high / CAN low).

Service robots on the rise

Service robots are extremely gifted, they can detect and interpret their surroundings, have the ability to learn, and ▷

are easy to teach. Flexible and autonomous, they are suitable for high-quality, individual services, including in a supporting function with people. “A service robot is a robot which operates semi- or fully autonomously to perform services useful to the well-being of humans and equipment, excluding manufacturing operations.” This is how the International Federation of Robotics (IFR) defines „service robots“. There are two kinds of service robots: personal and professional. A personal service robot is used for non-commercial tasks, usually by laypersons. Examples are domestic servant robots, automated wheelchairs, personal mobility assist robots, and pet exercising robots. A professional service robot is used for commercial tasks, usually operated by a properly trained operator. Examples are cleaning robots for public places, delivery robots in offices or hospitals, fire-fighting robots, rehabilitation robots and surgery robots in hospitals. In this context an operator is a person designated to start, monitor, and stop the intended operation of a robot or a robot system. The robot system comprises robots, end-effectors, and any machinery, equipment, devices, or sensors supporting the robot performing its task. Since service robots don’t require very high-speed networks but a low-power consuming network technology, which is reliable and robust, CAN is the ideal solution as an embedded network.

Service robotics is booming. At the Automatica fair this year, companies introduced their researches and developments on service robots. According to the event organizer, about 10 % more visitors and 7 % more exhibitors attended the fair in comparison to 2012, which shows that the topic “robotics” is becoming more and more established. Figures provided by the IFR also attest to a considerable growth potential. At least 93 800 new professional service robots will be sold between 2012 and 2015, worth €12,5 billion. There are approximately 100 000 professional service robots in use today. Medical robots are the leading sector with a sales growth of 20 % in 2012 compared to 2011. Service robots are above all often used for computer-assisted and image-guided surgery, where the average price of a robot ranges around US$1,5 million. Robots for supporting senior citizens and persons with disabilities are en vogue. They provide therapy and training, improve physical and cognitive functions, or serve as intelligent prosthetics. Driverless transport systems for intralogistics are becoming popular, for which the highest growth rates are predicted together with medical robots. Navigation technologies are decisive, ▷

Figure 2: After going in the box the stainless-steel robotic arm moves under the cow, scans it with lasers to find the teats, and attaches four teat cups

Figure 3: The Care-O-bot sweeping up dirt; it could even clean your office

thanks to which mobile robots can navigate independently in an unstructured environment, detect, interpret, and classify it as well as track objects. Especially milking robots are finding a lot of use in the agricultural sector. In addition, field robots account for 33 % of professional service robotics. Although robots can handle many tasks in agriculture and forestry such as harvesting, spraying, planting, and cutting, the requirements are very complex, so that a lot of development work is needed to really master all applications combined in agricultural engineering. Building and demolition systems, robots for professional cleaning, inspection and maintenance systems, robots for rescue tasks and underwater systems are increasingly in demand. "Among others, strong growth sectors are mobile transport vehicles for various areas such as hospitals and mail-order business as well as robots in agriculture and medical robots," according to Martin Haegele from Fraunhofer IPA. "In addition, robots are getting a stronger role in inspection and maintenance areas, security and rescue tasks."

The IFR estimates that from 2014 to 2016 robot installations will increase by 6 % on average per year: about 4 % in the Americas and in Europe, and about 8 % in Asia/Australia. The trend towards automation continues to increase the volume of robot installations. But the rate of increase in robot sales will be more moderate. Impulses will mainly come from the emerging markets and from the United States. At a press conference at this year's Automatica fair, Arturo Baroncelli, president of IFR, announced that 179 000 industrial robots were sold in 2013. That is 12 % more than in 2012, which means a new record for the robotic-industry. According to the Sparc, which is the partnership for robotics in Europe, the size of the robotics market is projected to grow substantially to 2020. From today's €22 billion worldwide revenues, robotics industries are set to achieve annual sales of between €50 billion and €62 billion by 2020. Today, robots have replaced many daily tasks of humans. Our world is becoming more and more automated. Robots could pervade most sectors of human activities, healthcare, agriculture, medicine, and consuming or military activities.

Robots for industrial cleaning

Schunk provides another example for service robots. Will the cleaning robot soon be as much a natural part of professional industrial cleaning as a sweeper or a steam cleaner? The Federal Ministry of Economy and Technology (BMWi) wants to explore, in the course of the joint "Plug & Play for automated systems" (AutoPnP) project, how robot-supported cleaning can be implemented, and if it can be efficiently transferred onto other robot platforms. This project is led by Fraunhofer IPA in Stuttgart, in cooperation with Dussmann Service. The project utilizes the standardized lightweight arm, a gripper hand, and an electric quick-change module from Schunk, a provider for gripping systems.

70 % of all costs that incur in professional industrial cleaning works concern the cleaning of floors and waste disposal. In order to automate this work, scientists at Fraunhofer further evolved the robot assistant "Care-O-bot 3", and programmed the necessary software functions with the aim that this mobile robot butler could also be used for cleaning business premises. It autonomously moves through the offices, and inspects the floor surfaces. Soiling is automatically detected, mapped, and cleaned with a cordless electric broom. If the attempt fails, since a dried coffee strain cannot be removed with a broom, the robot marks the position of the soiling on its map, and informs the cleaning personnel. Moreover, the robot can recognize wastepaper baskets, inspect their fill level, and empty the contents of full wastepaper baskets into a collection bin. A power-ball lightweight arm and a multi-purpose SDH-2 3-finger hand by Schunk are used for handling the wastepaper baskets, and the positioning of the cleaning trolley for the necessary endurance and the required freedom of movement.

The lightweight arms are specifically designed for such mobile applications. They are robust, designed for relatively high payloads, and due to the 24-V technology they are mobile. In daily operations they are economical: the energy required for a 100 W bulb of ▷

Figure 4: The lightweight arm is able to empty a full wastebasket

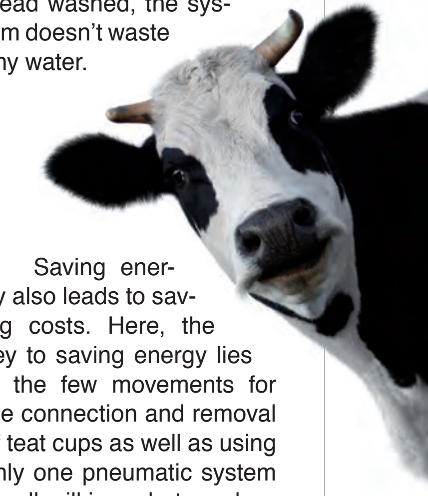
the past is enough today for the operation of a complete light-weight arm. Its light-weight, highly rigid design increases energy efficiency, and in the case of mobile applications it pays off in terms of longer runtimes.

At a repeat accuracy of +/-0,1 mm, the lightweight arm offers the optimum prerequisites for precise handling. Since the drive amplifiers and controllers are directly integrated in the modules, they don't need a separate cabinet. Moreover, the system architecture is designed in an open way. Via a flexible electrical and data interface concept, the arms can be integrated into various plant controls.

In order to be able to operate with maximum flexibility, Schunk has developed an electric quick-change module for this project, which puts the robot into position to flange other tools instead of the gripper hand, for example a cordless electric broom for cleaning the carpet. The quick-change module with its integrated 24-V technology opens up new scopes for the flexible use of various effectors in the field of mobile service robotics. Via a quick-change module with integrated CAN system, the gripper hand, the cordless electric broom, and other tools can be centrally controlled by the robot. For the implementation in the firmware the following specifications were used: CiA 301 (CANopen application layer and communication profile) and CiA 402 (device profile for drives and motion control). For the configuration of module-IDs and the bit-rate, LSS (layer setting services and protocols) is used as specified in CiA 305. Communication speed is 1 Mbit/s. Two CAN network cables, one for EIA-232 with one 5-pin M12 connector, and one 9-pin D-sub connector (to connect to a robot control device) are used as connectors. In order to ensure that the cleaning robot really meets the requirements of commercial use, the project is being executed in close cooperation with the cleaning specialist Dussmann Service of Berlin. A modular software structure that allows easy integration of hardware and software components, ensures that the solution can later be adapted to the field of application, and then transferred to cost-efficient robot platforms.

Back to robotic milking

Cost efficiency is also a good point regarding the introduced milking robot in the beginning of this article. Yes, the robot is quite an investment. But it is not just the initial investment that counts, but all costs in the years to come. The company claims the system only requires a maximum of four maintenance calls per year, and because there is no need for floor cleaning as milk cups cannot drop to the floor and udders are brushed instead washed, the system doesn't waste any water.



Saving energy also leads to saving costs. Here, the key to saving energy lies in the few movements for the connection and removal of teat cups as well as using only one pneumatic system for all milking robots and related equipment in the barn, such as selection gates. Jean-Philippe Côté, a farmer from Canada, said: “With the Lely Astronaut the efficiency of production costs such as water, soap, electricity and feed is excellent.”

Cindy Weissmueller

Table of contents

Mechanical assistants with embedded CAN networks

For farmers the day usually starts at 3 or 4 o'clock in the morning. They have to look after their cattle, feeding and milking them. Until now: Thanks to a milking robot, the cows milk and feed themselves.

Applications

System design

Tools

Devices

Business

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Imprint

Publisher
CAN in Automation GmbH
Kontumazgarten 3
DE-90429 Nuremberg

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www.can-cia.org
www.can-newsletter.org

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

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AG Nürnberg 24338

Printed in Germany
Hard copies: 3000
Soft copies: 3000

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Tips and tricks for the use of CAPL (part 2)

The first part of this series of articles addressed fundamental concepts of the CAPL programming language. This second part explains the time behavior of event procedures.

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CAN Newsletter (print)
Tips and tricks for the use of CAPL (part 1)

The second part also offers tips for all types of users so that they can work more effectively with CAPL in the areas of "generic programming" and "conditional compiling."

Execution model

A key difference between CAPL and C or C++ relates to when and how program elements are called. In C, for example, all processing sequences begin with the central start function *main()*. In CAPL, on the other hand, a program contains an entire assortment of procedures of equal standing, each of which reacts to external events:

- Triggered by the system: These events include those that are useful for initializing and post-processing the measurement run: on *preStart, on start, on preStop* and *on stopMeasurement*, as well as the time control and keyboard events *on timer* and *on key*.
- Triggered by bus communication: There are many different types of event procedures that react to bus events such as those related to communication or error handling, and they are very dependent on the bus type. Examples of these are *on message* and *on busOff* in CAN and *on frFrame* and *on frStartCycle* in FlexRay.
- Triggered by access to a *Value Object*: Such objects include system and environment variables that are globally available in CANoe and CANalyzer as well as signal values that represent a data interpretation of the bus communication. Special databases perform the interpretation. Part 3 of this series will address this concept.

Event procedures are atomic: The simulation model of CANoe is event oriented. In event procedures, CANoe executes all actions simultane ously from the model perspective, namely at the point of in time of the triggering event. The actual computation time on a real PC is ignored.

Simulation time and time stamp: However, a real event generated by the PC, such as a bus output by *output()*, gets a time stamp of the real-time clock. The sequence and time points of these events can be influenced by bus protocols, driver, and hardware properties.

On a simulated bus, some of the mentioned influencing parameters are eliminated. In this case, bus events are initiated simultaneously; in the case of CAN, for example, this leads to a dependable arbitration of multiple messages that are output by *output()*.

Updating system variables: Users can also use CAPL to modify environment or system variables that are visible outside of the program. CAPL does not propagate value changes to a variable until after the current event processing is finished, but with the same time of the just handled event. A read access within the current procedure always returns the old value even if the variable appears to be set to a new value within the same procedure. The advantage is that only one value change occurs at a single point in time.

The execution model is situation dependent: There are many ways to use CAPL in CANoe and CANalyzer, and so the execution model varies somewhat, too: The simulation nodes of a CANoe simulation are in parallel on the bus. Hence, they are completely independent from each other. Triggered events are always dispatched to all programs. In contrast, nodes in the measurement setup and in CANalyzer are processed in sequential order: Each node passes its output to the next. Incoming events must be passed to the next node explicitly for further processing. The procedures *on ** and *on [*]* are provided for this purpose.

Another type of program is a test program whose test procedures can wait for external events. CAPL resumes execution with the simulation time of such events. In contrast, waiting in normal event procedures stalls the entire simulation system. This is a frequent source of errors when CAPL is used. It is therefore inadvisable to use a busy-wait or wait command in an external DLL.

Efficient programming in CAPL

The preprocessor is a powerful tool in the C language, ▷

but it can also lead to confusion and consequently to errors. Therefore, only a subset of the well-known preprocessor directives in C is offered in CAPL with comparable semantics.

#include: Include files contain arbitrary but complete sections of a CAPL program: *includes*, *variables* and *procedures*. In contrast to C, the text of an include file is not simply inserted into the CAPL file, rather the sections. All sections of the included file apply to the entire parent CAPL file "as if" they were contained in that file. The sequence of sections is irrelevant in CAPL anyways. This means the compiler reports any duplicate symbols as an error. Moreover, code and data from included and parent files may use each other mutually. One exception to the just stated prohibition of duplicate symbols is that *on start, on preStart, on preStop* and *on stopMeasurement* may coexist in both the included file and the parent file. In these functions, the code is executed sequentially: first the code from the included file and then the code from the parent file. This means that the Include files are used to perform three tasks: declare data types, define variables and provide an (inline) function library.

#pragma library: CAPL programs can use Windows DLLs created in other languages, as long as they implement a suitable CAPL DLL interface. These DLLs can be directly linked with the directive *#pragma library("capldll.dll")*.

Macros: In CAPL, there are a number of predefined macros that are available to users for use in the code or for conditional compiling. Macros for use in the code can be used anywhere in the code without restriction. In contrast to C, macros may be used freely within string constants, identifiers for variables, and function names. They always begin and end with a % character, and they are primarily used to write generic programs.

Available code macros include the node name, index of the current channel, name of the current network and the type of bus being used. The code can access the name of the containing file with *%FILE_NAME%*, or it can access the name of the program file currently being compiled with *%BASE_FILE_NAME%*. In the case of Include files, the latter is the parent file. Here are two simple examples:

```
write("The node name"
" is %NODE_NAME%");
@Ch%CHANNEL% = 1;
```

There is a separate set of predefined macros for the conditional compiling of code sections. They are *#if, #else, #elif* or *#endif.* Within a program, they allow distinguishing between the program types simulation node, measurement node and test program as well as the CANoe version that is used. Here is an example that uses a *#pragma message*:

```
#if (TOOL_MAJOR_VERSION
== 7 && TOOL_MINOR_VERSION
== 5 && TOOL_SERVICE_PACK
< 2) || CANALYZER
#pragma message("This
program needs at least
CANoe 7.5 SP 3")
#endif
```

#pragma message: The *#pragma* message directive lets users output their own message during the compiling process, e.g. the version number of the currently compiling CAPL program. It appears together with the other messages, warnings, errors, and general messages of the compiler. ◀

Decoding data from a vehicle's CAN network

One of the most difficult questions for CAN tool suppliers is "How do I decode the data from my car?" Depending on the application and level of expertise of the questioner, there are many answers.

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To the novice user, it is difficult to know what data is easily accessible. Even engineers that work on targeted areas of vehicles, such as calibration, are unsure as to what data is available on the CAN network or how to decode it. There is a series of questions to determine if a solution is possible for their needs.

Do you want to decode normal messages or diagnostic messages? There are two major functions of networking in cars: system and diagnostic. The original usage for networks on vehicles was for diagnostics, but the majority of messages seen today on a vehicle network are for systems usage – information sharing and control. As an example, the engine broadcasts its speed message for display on the instrument cluster or to trigger the door locks to engage.

If the desired information is embedded in the system messages, then the easy answer is: "Please contact the vehicle manufacturer for those proprietary definitions." Manufacturers create their own definitions for data in these messages and do not publish the database. For users with a higher level of expertise, a 'roundabout suggestion' of reverse engineering or searching the Internet for a database solution might be appropriate. But in most cases, CAN tool suppliers sign Non-Disclosure Agreements (NDAs) and cannot provide the database of definitions.

Is the diagnostic data non-emissions-related (non-legislated) or emission-related (legislated)? The non-legislated (or enhanced) diagnostic data supports service repair applications, while legislated (OBDII, E-OBDII) diagnostics contain the emission-related information driven mandated by individual governments for cars sold in their countries.

It is easier to work with non-legislated diagnostics rather than system data, because there is a message framework, referred to as a service, defined for non-legislated messages within ISO 14229 Road Vehicles – Unified diagnostics services (UDS) and ISO 15765 Road Vehicle – Diagnostic communication over Controller Area Network (DoCAN) standards. But the data is mainly proprietary definitions from automotive companies. As an example, a service tool will use a specific service to request information from an ECU, like Service 0x23 - ReadMemoryByAddress. It is easy to construct the CAN message requesting the data of any memory address, but the definition of the data at that address is unknown – and varies from vehicle-to-vehicle. For these messages, once again, the answer is: "Please contact the vehicle manufacturer for those proprietary definitions."

Figure 1: The ELM327 hardware interface and its available displays for data

Do you only need data readily available on the network? The legislated OBDII data called PIDs (parameter IDs), while limited, is the easiest to obtain. The requirement of OBD (On-Board Diagnostic) systems is to give the vehicle owner or repair technician access to the status of the various vehicle sub-systems. OBDII uses master-slave communication, with the off-board tool acting as the master, or requestor. It is important to know that information doesn't just appear on the network; it has to be requested every time it's needed, therefore the tool used must be able to send these requests.

For novice users, such tools exist and are ▷

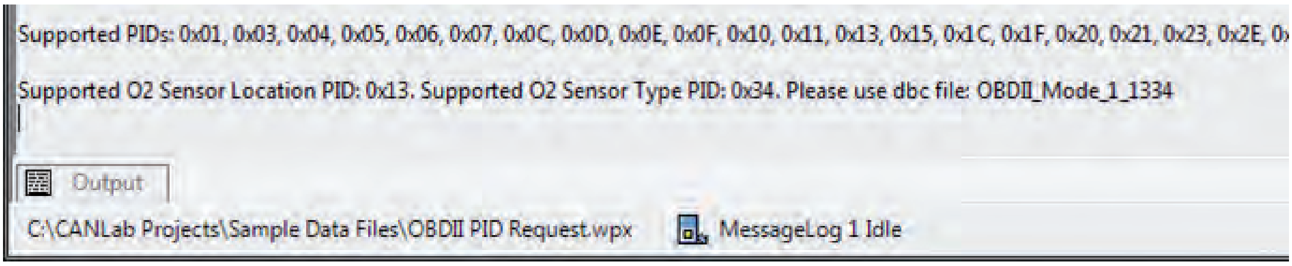

Figure 2: CANLab script display resulting from the Alt-S command

readily available on the market. Some are cheap and inexpensive, such as the Torque Android App using an ELM327 hardware interface. This easy-to-setup interface displays live OBD engine data on a phone or tablet. It is highly graphical and requires no low-level bit-byte knowledge at all.

More advanced users would be interested in a CAN analyzer tool to gather PID data, perform analysis, and port it into different applications. For example, Accurate Technologies Inc. (ATI) also offers a CAN development software solution, the CANLab Network Analysis Software. Working with the ATI CANary hardware, Kvaser CAN Interfaces, or other CAN hardware to physically interface with the CAN network, CANLab comes with a scripting application that can make requesting and viewing OBDII data relatively easy.

One example CANLab script that ships with CANLab allows users to emulate an OBDII tool easily. But again, OBDII has some variances that need to be understood by any tool, such as, setting up the PIDs, adjusting the CAN ID, and choosing the proper message send rate.

It is important to know that not all vehicles support all PIDs, so discovering what is supported is the first priority. The decoding of the data is also variable, so this CANLab example is supplied with six database options. Once the script is running there are two commands required for viewing data:

- Alt+S sends a Mode $01 PID 00 message request to determine which PIDS are available. The CANLab script displays the response with the PIDs in its output window along with the preferred database. The user then has to add the identified database to the CANLab project. The PID list also needs to be configured in the script.
- Alt+P starts/stops requesting the PIDs discovered.

The default (and most commonly used) CAN IDs used in the CANLab script are 0x7DF for the request and 0x7E8 for the response, but it may be necessary to adjust these CAN IDs as well. The request CAN ID can be changed in the script, while the response CAN ID is noted in the database. `

The other adjustable parameter is the message send rate (defaulted to 50 ms in the program). Different vehicles respond to OBDII requests at different rates. Typically, if the rate is too fast, many vehicles will not respond to a new PID received while processing a previous one. Using the CANLab Trace window to determine the response time, the request rate can be adjusted to smooth out the data request.

Vehicle networking solutions continue to evolve. While some networks were adopted from other industries, CAN was specifically designed for automotive and has had staying power. The most notable recent change is the latest addition of the Ethernet physical layer; included in ISO 14229-2 as the diagnostic communication over Internet Protocol (DoIP).

Another on-going development is WWH-OBD, or the World-Wide Harmonized On-Board Diagnostics, being specified in ISO 27145-2 and ISO 27145-3. Prompted by a United Nations' Global Technical Regulation (GTR), this specification is a further merging of the legally required and OEM-specific diagnostic contents – to become the single communication standard for access to OBD-related information. This could significantly simplify the viewing and understanding of ODBII data for everyone. ◀

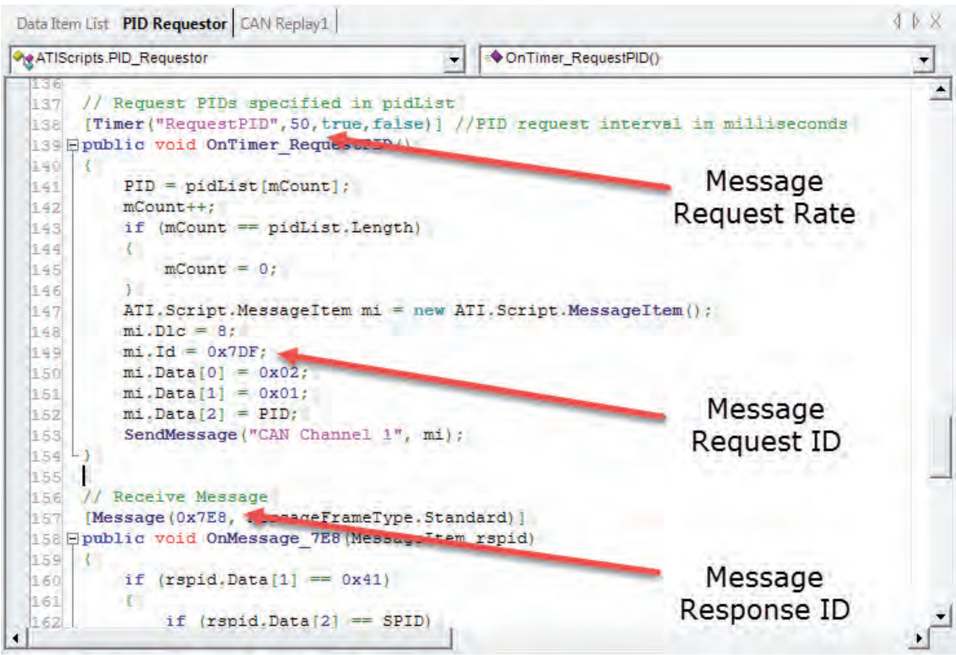

Figure 3: Location of the Message request Rate, Request ID and Response ID in the CANLab script

Loop detectors for traffic light systems

Traffic lights have been around for exactly 100 years. While the first ones were operated by hand, some of today's traffic lights communicate via CAN and can measure data of passing cars.

Swarco has developed loop detector devices, which communicate via CAN networks. The IG746 detects road vehicles, in order to classify them or to measure the speed. The IG946CAN is a four-channel loop detector and can be mounted on a DIN-rail. The Loop-Master software is used to put the detectors into operation and for diagnostic and service purposes.

The IG746 is an inductive loop detector for the connection of up to four inductive loops and was specifically developed for traffic applications. It comes with a CAN interface. The bit-rate is automatically recognized in the range of 10 to 500 kbit/s when the traffic light controller starts sending CAN messages. The node address is assigned by means of pins on the terminal strip.

The CAN protocol is specifically designed for traffic control applications. Typically transmitted data includes detection status, error status, and detection edges with occupancy time respectively time gap. In the optional version for double loop systems additional data such as vehicle speed, length, and direction are transmitted. Via the CAN interface parameterization of the detector and firmware updates are also possible.

The detector processes the loops one after the other in a predetermined sequence (multiplex mode); i.e. there is always only one loop switched as inductance L to the LC oscillating circuit of the detector. Since at any time only one loop has current flow, the channels of a detector cannot interfere with each other.

Figure 1: One of the first electric traffic lights in Germany: Installed in 1924, the five-edge semaphore tower in Berlin was equipped with lamps from Siemens operated by hand by policeman in the tower

If a metallic object is located within the range of action of the connected induction loop, the frequency of the LC oscillator also changes owing to reduction in the loop inductance. This change is determined by the detector evaluation circuit and, if the turn-on threshold is exceeded, a busy signal occurs on the switching outputs of the channel (electronic relay and open collector). Different output functions, e.g. presence signal and pulse signal are possible.

The detector is configured using the serial EIA 232 interface on the front of the unit. The PC service software Loop-Master provides an operator interface for modifying and displaying all parameters and diagnostic values. The configured parameters are stored in a non-volatile memory (EEPROM).

The IG946CAN is used for signal output in traffic light installations via CAN and switching outputs as well as for traffic counting. The detector is designed for DIN-rail mounting and includes an overvoltage protection module for the inductive loops. It is an inductive loop detector for the connection of up to four inductive loops and was specifically developed for traffic applications. CAN bit-rate and node address setting is the same as with the IG746. Also the transmitted data is similar to the above-mentioned detector. Of course, the same PC service software can be used. Optionally the four-channel detector provides, when using a double-loop configuration, data on the speed, length, and driving direction of the detected road vehicle.

The detectors are also connectable to the Actros. compact traffic light controller via CAN. The compact device is designed for smaller junctions and pedestrian crossings. Due to further developments of the Actros controller technology, the compact version features all original properties. Control cores and peripheral modules such as fault sensors and audible ▷

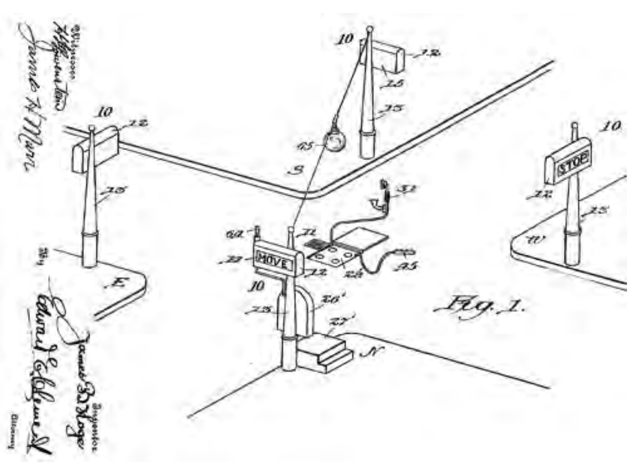

Figure 2: In 1918, James Hoge was granted a patent on a municipal traffic control system consisting of four pairs of red and green lights (US 1 251 666)

100 years of traffic lights

On August 5, 1914, the American Traffic Signal company installed an electrical traffic signal system on the corner of East 105th Street and Euclid Avenue in Cleveland, Ohio. It had two colors, red and green, and a buzzer, based on the design of James Hoge. The design allowed police and fire stations to control the signals in case of emergency.

Various competing claims exist as to who invented the world's first traffic signal. In 1868 in London, a two-semaphore arm was installed that extended horizontally to signal "stop" and at a 45-degree angle to signal "caution". In 1912 in Salt Lake City, Utah, Lester Wire, a police officer, mounted a handmade wooden box with colored red and green lights on a pole, with the wires attached to overhead trolley and light wires.

Nowadays, modern traffic lights are part of traffic monitor and management systems. Some of them use embedded CAN networks, e.g. to connect loop detectors and other devices to the cross-section controller.

"green light" signals for blind pedestrians can be integrated. The unit provides 24 outputs, which can be toggled and monitored independently of each other. Information can be imported and requests can be toggled via 12 inputs and four outputs. The control panel is directly integrated into the front panel (as a default setup) where program and error information is displayed. Operation via durable touch sensors enables switching on/off and the changeover of programs and control levels. Traffic engineering is generated via Lisa+, the company's programming language, or via Java programming.

Other products using CAN connectivity includes the "Life" LED tunnel signs. Another CAN-connectable device is the SCC-Air processing unit. The ARM-based controller runs Linux and can be combined with the Swarco Motorway Controller software. The KSR public transport priority system is also equipped with an embedded CAN network.

Expanding business

The Austrian enterprise recently acquired Technical Traffic Solutions (TTS), a Danish 35-employees company. The activities of TTS will be integrated with Swarco's operations in Denmark. Hans Petter Ødegaard, Oslo-headquartered Swarco Nordic's managing director, regards the acquisition as an important step to consolidating and expanding the position in Denmark and beyond: "With the acquisition of TTS we have reinforced our presence and prepared for further long-term growth in the Danish market. We have achieved a constant annual growth in the Nordic ITS market over the past 10 years and are convinced that the acquisition of TTS will further contribute to this development". Swarco has also acquired the British APT group based in Harrow (Middlesex). The 170-staff company is focused on parking access control and payment systems, electric vehicle charging, etc. *Holger Zeltwanger*

CiA in Poland: only a few members

Currently, CAN in Automation (CiA) has three members with headquarters in Poland: Diga, Obrum Gliwice, and Polchip. For several years CiA has supported Obrum in organizing the biannual Polish CAN conference.

Links
www.diga.biz.pl
www.obrum.gliwice.pl
www.polchip.pl

This year the "Konferenzja CAN" happens for the 6^{th} time on September 18^{th} and 19^{th}. For the first time the event will not take place in the health resort town of Ustrón close to the Czech and Slovakian boarder but at the Arsenal Palace Hotel in Chorzów, which is a city in Silesia in southern Poland, near Katowice. Chorzów is one of the central districts of the Upper Silesian Metropolitan Union – a metropolis with a population of 2 million. At the conference, CAN experts and newcomers gather to exchange knowledge and experiences. One of the main objectives is to bring researchers and industries together. Obrum, member of CiA since 2006, once again organizes the conference "Application of the CAN bus in military and civilian technology" providing a platform for exchanging information between representatives of three complementary areas of activity: industry, research and development centers, as well as scientific centers, and last but not least producers/distributors of devices and equipment using CAN. CiA's managing director Holger Zeltwanger is a member of the program committee of the conference and also a speaker.

> *Polish universities have used CAN in many academic research projects.*

At the 5^{th} CAN conference in Poland, Diga presented its CANstudio 3, a CANopen analyzing and configuration tool. After asking Jacek Barcik from Diga why the company became a CiA member back in 2008, he said it was to be up to date on what is new about CAN and CANopen all the time and also to get a CANopen vendor-ID "free-of-charge". This vendor-ID is part of the object 1018_h and identifies the manufacturer of a device uniquely. It must be implemented in all CANopen devices. Jacek Barcik also said another reason to became a member was to get access to all CiA specifications. Diga is a manufacturer of CAN tools and customized CAN interface boards. The company also offers CAN training and R&D and is a distributor of controllers from Intercontrol for mobile use and CANopen products from Microcontrol in Poland. The application fields are transportation (off-highway vehicles), manufacturing (embedded machine control), construction (road construction machines, building construction machines), agriculture, and forestry (tractor, forest harvester). One of the company's products is the ▷

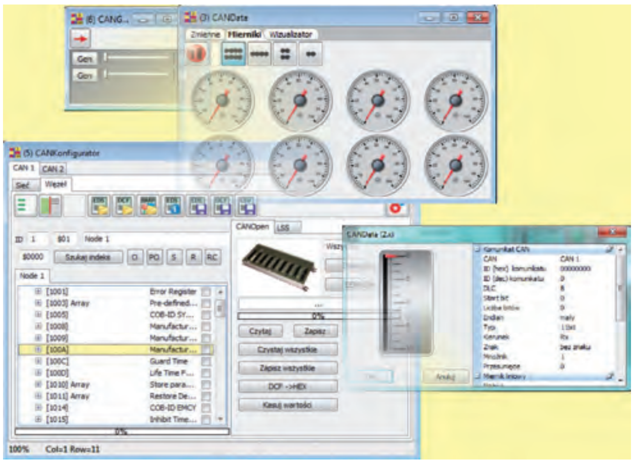

Figure 1: The CANstudio 3 is suitable for configuration, diagnostic, and service purposes; it can interpret CANopen protocols (Photo: Diga)

Figure 2: The Ibis is a six-wheels robot for pyrotechnic and combat missions (Photo: PIAP institute)

CAN Newsletter Online
5^{th} CAN conference in Poland

CRUSB – CAN/USB converter. It is designed for translating information from CAN to data stream transferred via USB. Due to its plastic casing and low energy consumption it is suited for use with mobile computers. The interface dongle provides two precise timestamps both for received and transmitted CAN frames. A free-of-charge CAN-Monitor and a DLL library are available. The company also offers the already mentioned CANstudio software tool, which can be used for configuration, diagnostic, and monitoring of CAN networks. On demand a CANopen node and custom software protocol are available. The tool can be used in conjunction with the CAN/USB dongle. With the tool one can build a multi-nodes CAN network virtually and save it on disk.

The third CiA member, Polchip, joined the nonprofit association in 2012. The company offers consulting, installation and service of parking systems, and solutions for parking management: for example single space counting, license plate recognition, lightning management. It also provides ticketing solutions for public and private transport and rail operations. According to the company, it still plans to only use CAN/CANopen in its parking systems.

Polish CAN applications

Poland, a member of the European Union since 2004, has some industries using CAN networks. Polish universities have also used CAN in many academic research projects. Two important markets are military and civil service robots, which were presented several times at CAN conferences organized by Obrum.

This company also offers tanks that use embedded CANopen networks. The PIAP industrial research institute for automation and measurements in Warsaw has developed several counter-terrorism robots, e.g. for removing explosives.

The 39-million people country is quite interested in CAN technology: 1,6 percent of the CAN Newsletter Online readers are from Poland. This corresponds to place 13 in the worldwide list. “We know that some Polish companies use CAN in rail vehicles and in maritime electronics,” said Holger Zeltwanger from CiA. Pesa, for example, has developed a diesel trainset with embedded CANopen networks. The company has also manufactured 120 trams using CANopen networks for the city of Moscow (Russia).

Cindy Weissmueller

Implementing CANopen Safety I/O modules

CANopen Safety is gaining acceptance in particular in mobile machinery. TTControl specializes in electronic control systems for this application field and has developed an I/O module featuring CANopen Safety.

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CANopen I/O modules can reduce the wiring effort for sensors and actuators, which are located far from the processing device. By using an I/O module the wiring between logic and sensors/actuators is reduced to the CAN network and the power supply. Aside from CANopen functionalities, the logic and control functions implemented on the I/O module are reduced to a minimum, e.g. a PID controller for current-controlled PWM outputs. Thus, the actual logic (e. g. safety functions) is executed by the participants of the CANopen network, which process the I/O data of the CANopen NMT slave device, e.g. the CANopen host controller with NMT master functionality.

All of the company's CANopen I/O modules are implemented on the basis of their general-purpose control units. The HY-TTC 30 family, for instance, is the basis of the HY-TTC 30X family of CANopen I/O modules. Their general-purpose control units are delivered with a C-driver library, which can be used by a custom application to control the I/Os of the device.

The CANopen I/O module implementation is actually an application programmed in C, which uses the existing drivers of the underlying platform. Figure 1 depicts this concept: The CANopen application (outlined in blue) controls the underlying hardware exclusively via the existing drivers of the platform (outlined in green) basing upon the configuration stored in the object dictionary. The CAN communication is handled via a separated CANopen stack, which also uses the CAN driver of the platform drivers.

Figure 1: The CANopen Safety I/O modules are intended for outdoor use in mobile machinery; they are certified for PL-d safety-applications (Photo: TTControl)

Integration and operation

The CANopen I/O modules are delivered with ready-to-run software and an electronic datasheet (EDS file), which makes integration into a CANopen network without any additional development effort for the I/O module possible. The CANopen application of the I/O module is essentially an interface to the underlying general-purpose control unit which implements error detection and safety mechanisms. The I/O module is typically integrated into the system by loading the EDS file of the device into the application of the CANopen master, e.g. via Codesys. The EDS file contains the definition of the CANopen object dictionary of the device and thus the description of all available features and configuration options of the I/O module.

Once the EDS file is loaded by the CANopen host controller, the developer simply chooses the desired I/O setup and fixes the data exchange between the master and I/O module by configuring the corresponding CANopen communication object. The inputs and outputs of the I/O module can then be used as if they were I/Os of the host controller.

Configuration and operation

The host controller can configure the I/Os of the CANopen module by ▷

writing the required configuration parameters to the object dictionary of the device via SDO (Service Data Object) services. All configuration options of the device, including the configuration of a pin-functionality (e.g. configure the pin for use as digital output, PWM output, timer input or analog input), modes (measurement of voltage, resistance or current if configured as analog input) and safety parameters (e.g. upper and lower voltage limits of an analog input; the limits are periodically monitored by the device), are reflected by dedicated entries in the manufacturer specific area of the object dictionary.

Similarly, dedicated entries exist, which contain the pin values of the CANopen I/O module. The I/O device updates the entries of the input process data in the object dictionary periodically. The host controller or other connected CANopen devices can retrieve these values via the corresponding CANopen communication objects. Typically the I/O module is configured to periodically transmit input data via PDO (Process Data Object) or SRDO (Safety-Related Data Objects).

Analogously, outputs of the I/O module are controlled by writing the required set-points (such as the duty-cycle of a PWM output or the level of a digital/voltage output) to the object dictionary using CANopen communication objects. The I/O module periodically checks whether the corresponding entries have been updated and uses the set-points to control the output. Typically the I/O module is configured to receive these set-points via PDO or SRDO.

Diagnostics and error control

The I/O modules autonomously perform diagnostic tasks (e. g. RAM-tests of the CPU, signal-range checks of I/Os, monitoring of board temperature) and check the I/Os for errors (e. g. short-circuit or open-load detection) – the developer using this I/O module is relieved from this task. This reduces the development effort of the application on the CANopen host controller to a minimum.

It is only necessary to check and monitor the status of the used I/Os. Additionally, the NMT status is observed. Similar to the pin values used to read input data and set outputs, dedicated entries exist in the object dictionary, which contains the status of each pin (e.g. pin is o.k., short circuit has been detected or open load is present). The host controller or other connected CANopen devices can retrieve the status via CANopen communication objects. Typically the I/O module is configured to periodically transmit the status data via PDO or SRDO.

In addition to these manufacturer-specific entries the CANopen I/O modules also support the error handling mechanism of emergency messages as defined by the CANopen specifications. The devices generate EMCY (emergency) messages in case of critical errors such as short-circuits (as specified in CiA 401) or manufacturer-specific events. An example for a manufacturer-specific event of the CANopen I/O modules is the activation of a protection mechanism, which prevents the device from damage (input and output protection).

By implementing both – the manufacturer-specific monitoring approach (retrieving status information by reading dedicated entries in the object dictionary) as well as the error handling mechanism of EMCY messages – the user has the freedom to choose which approach to use.

Implementing CANopen Safety

The HY-TTC 48X and HY-TTC 36X families are the company's first CANopen Safety devices. The HY-TTC 48XS module meets the necessary safety requirements of ISO 13849-1. It has been certified for PL-d (performance level) according to ISO 13849-1 by TÜV North (Germany). The HY-TTC 30XSH and HY-TTC 30XSI safety variants are subject to certification according to PL c of ISO 13849-1. The CANopen Safety I/O modules are based on single-channel software architecture and support safe communication via CANopen according to EN 50325-5 via a single CAN channel.

A fundamental part of the safety concept of the CANopen I/O modules is the fact that they are developed as pure software applications on top of the matching, certified general-purpose ECUs. The majority of the safety requirements are implemented by this safety platform whose safety concept and parameters (e.g. assumed safety function, performance level and diagnostics as well as safety critical system components) match the ones of the CANopen safety I/O module.

The underlying certified safety platform executes all diagnostic measures such as the required fault-detection mechanisms to achieve the required diagnostic coverage as well as internal checks of the CPU – independent of the actual application. The safe execution of the actual application is also ensured by the safety platform by executing internal tests of the CPU (such as periodic tests of the CPU registers, stack checks, RAM tests and a CRC check of the flash) and by the ECU architecture itself (e.g. 1oo1D architecture with the corresponding test equipment such as a watchdog). The currently available CANopen I/O modules feature a microcontroller of the Infineon XC2000 series. The HY-TTC 48XS, for instance, uses the XC2287M microcontroller, which features an integrated ECC test to protect the RAM and therefore allows to assume that all data in the RAM is protected against bit-flips (the device activates the safe-state in case such a bit-flip is detected).

Thus the main responsibility of the CANopen application software is essentially only to safe the CAN communication channel as specified in EN 50325-5, e.g. by activating the safe-state in case of a loss of communication caused by a cable break on the CAN-lines. The application uses single-channel architecture, i.e. no software parts are executed redundantly (neither in time nor by software diversity).

Requirements for the system designer

A safety manual is provided to the system integrator, in order to ensure the correct integration of the CANopen safety I/O module into the overall functional safety concept of the safety system. These requirements have to be fulfilled to reach the specified level of safety integrity.

The safety manual also includes requirements for the safe configuration of manufacturer-specific device parameters such as pin-configurations and modes, which are not covered by EN 50325-5. For compatibility reasons between safe and non-safe CANopen I/O modules as well as third-party CANopen configuration tools the CANopen I/O modules do not require specific configuration mechanisms (such as the calculation of CRC values) for the safe configuration.

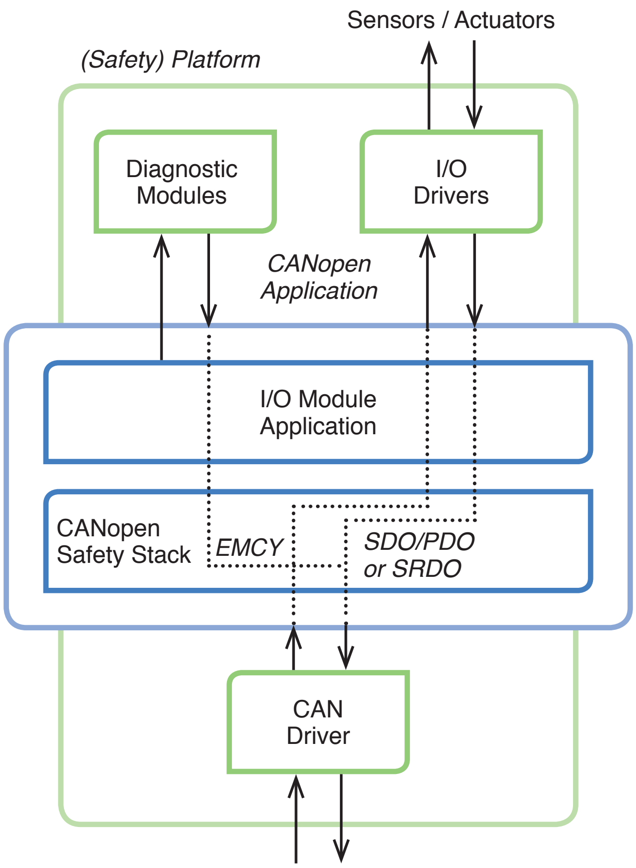

Figure 2: Basic outline of the concept used for the TTControl CANopen I/O modules (Source: TTControl)

Instead, the safety manual specifies a certain sequence, which has to be followed for the configuration if the device is used in safety-related systems:

- By default, all configurable pins of the CANopen devices are disabled (set to "not configured"). Thus the device has to be configured before use by writing the corresponding entries in the object dictionary.
- The device is configured by using the general CANopen configuration sequence (such as for PDOs), i.e. by using SDO services to write the required settings to the object dictionary.
- In order to ensure that the device has not received wrong values, e.g. due to bit-flips in the CAN frames containing the configuration data, all settings have to be read back and compared to the desired settings. The configuration has to be repeated if there are any errors.
- Once configured, the device has to be instructed to store the configuration in its non-volatile memory by writing the proper values to the CANopen parameter (1010h as specified in CiA 301).

The device stores the configuration redundantly and with CRC protection to provide the proper error detection. Upon start-up the device checks the consistency of the configuration; during run-time the configuration data is inherently protected by the underlying safety platform (amongst others by periodic tests of the RAM).

Specifying such a configuration sequence allows a certain degree of flexibility: In the prototyping phase of a system it is still easily possible to even manually configure the device. This would not be trivial if, for example, it was required to write ▷

a CRC calculated over the device configuration to the object dictionary. It also facilitates the transition from a normal CANopen I/O module to a CANopen Safety I/O module. Also, the implementation of such a configuration sequence in a configuration tool is extremely simple. Finally, the system designer may decide to use a different mechanism to verify that the device is correctly configured, e.g. by executing run-time tests via a CANopen host controller.

Compliance and device classification

The CANopen I/O modules comply with CiA 301 and CiA 305. The safety variants furthermore comply with EN 50325-5. All of the company's CANopen I/O modules are classified as "generic CANopen I/O modules" according to the CiA 401 CANopen device profile CiA for all standardized features such as digital I/Os. They provide the required entries in the object dictionary and also implement the specified error control mechanisms. Furthermore, CiA 401 specifies optional CANopen features such as interrupt-driven transmission of PDOs. Only a subset of I/O modules implements this feature.

CiA 401 also specifies an optional standardized PDO mapping, in order to provide plug-and-play functionality. This is advantageous for devices with limited configuration options. But the products feature a high-degree of configurability, which makes it very unlikely that a pre-defined PDO set-up matches the actual requirements of a system. This does not violate the CANopen conformity because in the device type parameter (object 1000h) the device-specific PDO mapping bit is set. At the moment, no pre-defined SRDO mapping is specified in the CiA 401 profile. Therefore, the safety variants of the CANopen I/O modules do not provide any pre-defined SRDOs, i.e. the devices do not send any SRDOs if not explicitly configured. ◀

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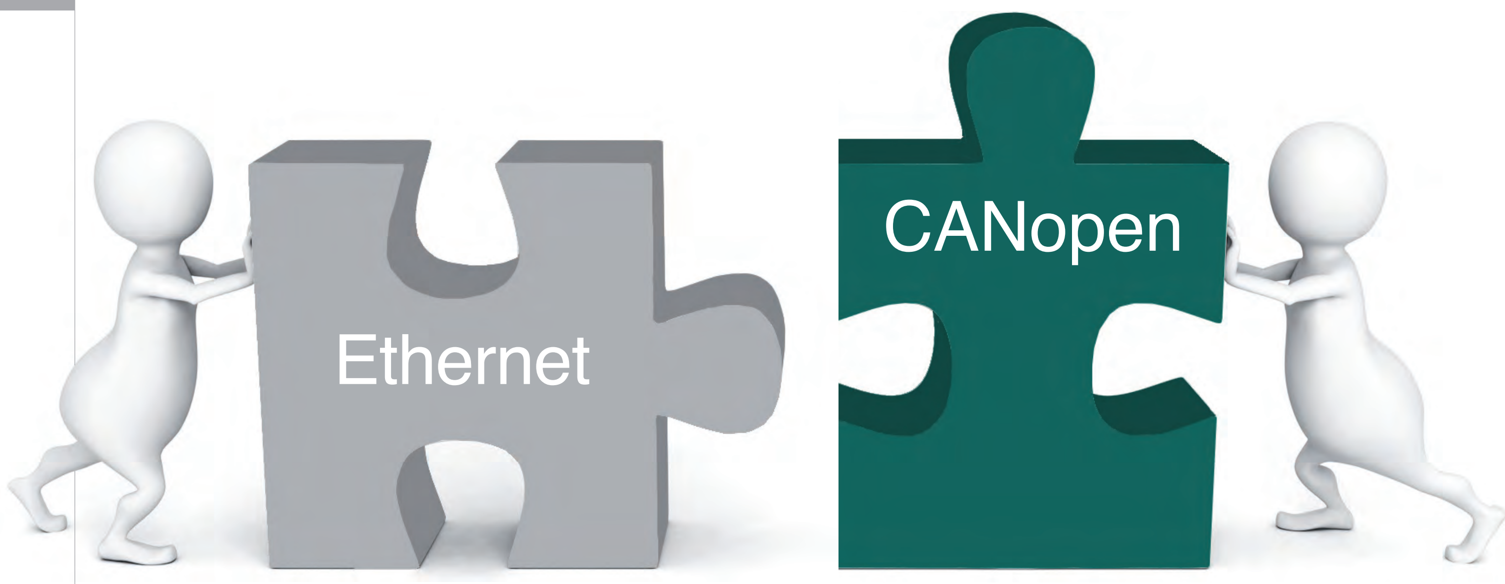
Combining Ethernet and CANopen

Whenever data needs to be communicated between a serial bus system and Ethernet, gateways provide the bridge. This solution is controlled via TCP/IP and supports CANopen PC cards as DIN-rail mountable devices.



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CANopen in industrial automation

Nethost, the latest gateway from Hilscher, offers a totally different approach to conventional solutions. Controlled via native TCP/IP, it supports the full feature set of Hilscher's standard CANopen PC card in accordance to CiA 301 but as a DIN-rail mountable device.

„It controls 1000 CANopen I/O's within a millisecond without requiring an own designated CANopen connection", would be a convincing advertising message for a PLC system offering only an Ethernet interface by design, while still providing full access to CANopen nodes devices. Nethost is „hosting" the missing CANopen interface as an Ethernet node. Thanks to the simplicity of the TCP/IP protocol and the high transmission range of 100 Mbit, this is a suitable replacement for conventional integrated serial bus system solutions.

Ethernet and so-called fieldbus hand in hand

The use of Ethernet for establishing a modern communication infrastructure offers high potential savings. Transparency of the system, uniform wiring standards, simple redundancy concepts to avoid downtimes and short processing cycles in combination with high deterministic are only some of the advantages of the Industrial Ethernet. Unfortunately though, machine designers have to choose between 6 different Industrial Ethernet protocols competing on the market in the meantime. Implementing and supporting any of them calls for high up-front investments in order to gain just a higher level of performance not often needed.

„Does it always need to be industrial-standard Ethernet? In most cases, maintaining the serial bus system still in combination with the simple office-standard Ethernet results in a sufficient solution too," commented Armin Beck, product manager for gateways at Hilscher, on the seemingly inevitable change. Indeed, it can make sense to continue using the potential of the already available serial bus system. For example, strict real-time response is usually only required by motion control applications. In more than 95 % of all other applications it is completely irrelevant. Processing cycles lower than a millisecond is only in very few cases required. Nethost is a feasible solution for all applications, where machine control via serial ▷


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bus system has proved to be a reliable concept and now intended to be operated remotely via Ethernet. It offers latency as low as 1 ms and the support of simple TCP/IP. The bandwidth of the 100 Mbit Ethernet is sufficient to allow safe simultaneous addressing of up to five such devices via one Ethernet line, which was proven by measurements.

Protecting investments in serial bus system devices

When looking at its sales history, Hilscher observes a clear trend towards Ethernet. Demand has risen considerably especially during the past two years. Yet, with a market share of over 70 %, serial bus system technology still holds a strong position and will continue to exist for many years. This also means that machine manufacturers will need to support both systems for quite some time, which the company took as a special challenge. „When discussing the concept for the new product, protecting investments was of primary importance to us," stated Beck and added: „It was therefore not our goal to simply replace the serial bus system with industrial Ethernet. Instead, we wanted to combine both technologies in a simple way to address a wider market and allow customers to continue using proven field devices." The ideal of a gateway based upon TCP/IP was born.

The CiA organization as well took account of the Ethernet trend and developed the standard CiA 309 dealing with the subject of "Interfacing CANopen with TCP/IP". As an immediate result, a few Ethernet to CANopen gateway servers emerged on the market redirecting and forwarding TCP/IP coded CANopen commands to the underlying CANopen system one by one, enabling its remote control over Ethernet. Nethost, however is different and not just a simple server. It includes a fully featured CANopen master that runs autonomously and takes care of all configured transmit- and receive-PDOs of its nodes by itself. All these PDOs then are offered in a compressed process data output and input image, a single Ethernet service grants access to. With the simplicity of this interface a Nethost user needn't care about all the CANopen services, the protocol handling and the configuration. This enables the effortless integration into conventional PLC systems used to operate with cyclic IO images anyway. Nethost furthermore maintains no CANopen object dictionary to be configured over CiA 309 services. Much simpler: the configuration is done as a whole and in one step with a graphical configuration tool.

Figure 1: The Nethost enables PC card 'slot-less' compact industrial PCs or other embedded systems connectivity to and control of serial bus systems over Ethernet (Photo: Hilscher)

Apart from the PDO transmissions the CANopen Nethost supports various CANopen specific services as well that can be instructed over Ethernet. Supported are SDO communications and NMT master operations. Nodes emergency messages are collected node wise in diagnostic buffers requestable by the Ethernet application as well. If necessary is it also possible to transmit and receive pure CAN telegrams to the network at any time by using COB-ID filtering.

Short time-to-market

TCP/IP as such takes care of safe transmission from and to the Nethost. The transparently transmitted telegrams are coded and classified depending on their purpose, adding only a few bytes to the header of the telegram. The coding is Hilscher specific. Using the standard proposals CiA 309-2 or CiA 309-3 for encoding the services over Modbus TCP or ASCII does not go far enough. Nethost is pursuing a global and serial bus system independent approach over all its supported serial bus systems such as Profibus, Devicenet and CANopen. A Nethost supports a watchdog function, which for example CiA 309 does not cover, bringing the underlying CANopen system into a safe state when the Ethernet application dies.

The coding logic is provided by Hilscher as part of a C source code. It is projected to a socket interface and is therefore compatible with any TCP/IP stack. On the side of the application, it is abstracted to a simple procedural serial bus system independent API interface. Simple functions, such as open, close, reset, send, receive or I/O-exchange guarantee a fast learning curve to allow shortest-possible integration times. Based upon the RPC principle, functions are decoded inside the device and processed remotely. In order to make it easy for embedded programmers as well, a DLL allows immediate use of the Nethost under Windows, while a C toolkit shows a sample implementation under Linux.

The Nethost's API access functions confirm to the Hilscher platform strategy and follow the basic principle „once installed – everything works" just like ▷

with Hilschers PC cards. For example, exchanging the Windows PC cards DLL against the Nethost DLL allows exchanging both product ranges without any need to change the application program. Both DLLs have the same API. Whatever was formerly controlled locally over a PC, can now be controlled remotely via Ethernet directly from the process control level. „Using the same API turns Nethost into a dedicated PC card for the switching cabinet. For systems without PC card slots, it even turns into a direct replacement for PCMCIA PC cards for example,“ Beck commented on the access via the Ethernet and added: „And if a system already supports our PC cards, it will automatically also support the operation of a Nethost.“

Hilscher was able to win two of its long-standing customers to integrate Nethost into their solutions. For many years, these companies had ordered high quantities of PC serial bus system cards to control their peripheral components. After 15 years, however, both of them announced to work on a new generation control solution, which offered more compact dimensions in combination with increased flexibility, but could only be addressed via standard Ethernet interfaces. Yet, they did not want to give up support of established serial bus system technology and looked for a migration path to their new product generation. Using a conventional TCP/IP stack and a standard Ethernet controller, while utilizing existing programming experience, these companies were able to offer system integration within a minimum of time. Today, they are in a position to serve both the existing base of serial bus system customers, as well as new Ethernet customers.

Future steps

The next step of the development of Nethost is already under way. In the 3rd quarter of the year, Hilscher will present three new models of its Nethost range on the market. The already existing models for CANopen, Profibus, and Devicenet will be complemented by models for Profinet, Ethercat and Ethernet/IP Master. In this way, Hilscher reacts to an increased demand for TCP/IP applications in the real-time Ethernet world. In general all models are configured via a serial bus system-independent uniform FDT/DTM-based configuration tool. In situations, where an engineering tool of the target system already exists, open configurations via standardized XML files are an alternative offering increased transparency. XML schemes turn the configuration data into the correct format and can be loaded into the Nethost after conversion into a binary file. In this way, the device can be fully integrated into any target system. ◀

Lock and load: LEVs for public infrastructures

Pedelecs, e-bikes, and other LEVs (light electric vehicles) are gaining acceptance: China is the biggest market with 28 millions sold in 2013. In Western Europe only 500 000 pedelecs will find a buyer this year.

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Figure 1: One-stop-shopping – Bosch is the market-leading supplier for electric and electronic pedelec and e-bike components, most of which provide CAN connectivity (Photo: Bosch)

"Bosch's success has made other automotive suppliers interested in the LEV market.

Most of the pedelecs (pedal electric cycle) developed and produced in Western countries use CAN communication to integrate motor, battery, charger, HMI, and other electronic units. Most of the Chinese ones don't use electronics. They offer no safety at all: Some batteries blow-up and burn-down cottages and houses. This would be a "no-go" in Western countries.

Today most pedelecs are charged at home using the charger coming with the battery. But the future may look different: Several tourist regions are prototyping pedelec rental systems including public charging stations (e.g. Tegernsee in Bavaria). The same is happening in some cities (e.g. Rostock, Barcelona, and Copenhagen). For such public charging infrastructures, standardized solutions need to be developed. The IEC has already started a standardization activity: Under the IEC 61851 series the IEC technical committee 69 will publish a technical specification of the CAN communication between charger and battery. CiA has submitted the related parts of its CiA 454 CANopen application profile for energy management systems. This includes the battery, the AC/DC converter, and the DC/DC converter with all the necessary pre-defined PDOs. The CiA 454 profile also intends to specify the CANopen communication of embedded pedelec units such as motor, lock, HMI, and gateways to other communication systems.

Bosch: dominant supplier in Europe

Bosch's pedelec motors drive about 300 000 LEVs in Europe. This is a market share of about 25 percent. The market-leading automotive supplier started in 2009 with the pedelec business. Engineers from the electric tools business and the automotive departments joined forces. In global terms, the pedelec business is still a very small part of the Bosch enterprise: the company produces 32 millions of electric tools and 80 millions of small motors for use in passenger cars. Nevertheless, the German company is investing into the pedelec future. Recently, the Active line and the Performance line of drives for pedelecs (up to 25 km/h) respectively for e-bikes (up to 45 km/h) have been launched. Available next year, they substitute the Classic line drives, which are no longer competitive. The production facility is in Miskolc (Hungary).

The success of Bosch in the pedelec business has made other automotive suppliers interested in the LEV markets. Continental, another German car supplier, will start mass production of electronic units for battery-powered two-wheelers soon. The company offers a complete drive system consisting of motor, display, control unit and battery. This modular system is positioned in the premium segment and is smaller, more powerful, and lighter than other concepts ▷

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currently on the market. The motor itself is small. It weighs just 3,4 kg and is integrated right into the frame. This makes for a particularly harmonious activation of the system and enhances riding comfort. Bicycle manufacturers can configure the system according to their needs. For instance, batteries are available for installation on the luggage rack or on the lower tube and in various capacities as well. Continental will set up a service network of its own to actively support OEMs and dealers.

"Our customers in the two-wheel industry obtain an optimally tuned benchmark system composed of high-quality components," noted Regina Arningfrom head of the Contitech Power Transmission Group. This department has been developing and manufacturing drives for motor vehicles, motorcycles and machine engineering applications for many years. "Our strength is in the area of systems integration. The nature of the frame makes this a very important issue in the case of bicycles. Manufacturers who opt for Continental drive systems do not have to alter the length of their standard frames." Continental designed the system together with its partner Benchmark Drives and is developing it for serial readiness. In the meantime, Continental bought its partner. After a successful sampling by OEMs, Continental will start production in the fourth quarter of 2014. Of course, the embedded network is CAN-based. Information from the CAN-based system can be accessed with complimentary software. Information on performance data, charging processes and user behavior will support system analysis and maintenance. Technical support is available through a hotline providing information about products and sources of supply. The service is operated at a central service center in Frankfurt. Training courses specially tailored to the needs of manufacturers and dealers will start in spring 2015. In 2015 at the latest, users will be able to buy LEVs equipped with the system. The goal is to garner a two-digit share of the e-bike and pedelec market.

Brose, a German manufacturer of electric motors for the automotive industry, is also entering the LEV market. In July, the company started serial production of LEV motors in Berlin (Germany). According to the company, it is the only supplier of drive systems "Made in Germany". The first customers include Bulls and Pegasus (both ZEG) and Rotwild. Brose has invested €3,4 million in the set-up of production capacities. "Today clearly marks a significant milestone in Brose's history as we celebrate for the first time the transfer of our group's technical expertise and values to a new market in exactly the same city where Max Brose founded his first company in 1908," said Michael Stoschek, Chairman of the Brose Group. "Our aim is to become the No. 1 supplier in the premium segment by offering top technology and quality, and then gradually enter the classes below. The expectations are high and encouraged the other shareholders and me to take this step and create the necessary technical and personnel conditions," he added.

Over the last three years, Brose's engineers have developed the drive system for e-bikes based on its steering motor for vehicles that had already been produced millions of times. In the beginning, they participated in the CiA 454 specification group. The launched drive still provides CAN connectivity, but the messages are proprietary, because in CiA 454 there is no drive interface specified yet. ▷

Similar to the development of cars, Brose has extensively tested the drive in laboratories and done some driving tests under extreme conditions in the Alps, covering more than 100 000 km since July 2013. Christoph Bantle working with Brose stated: "Our motor runs virtually silent and vibration-free. The highly sensible sensor system ensures smooth, yet powerful pedal assistance, thus addressing different target groups.

In addition to the in-house manufactured drive, the company also offers customized complete systems on request. Manufacturers can choose from a range of components required for the design of an e-bike: from display- and wiring-harnesses to fixtures welded to the bicycle frame. The batteries are supplied by BMZ (Germany). It is possible to integrate the drive and battery into the frame depending on the customer's requirements and to adjust the housing covers individually. The driving behavior can also be customized: for instance, the delay in pedal assistance activation and intensity can be varied depending on the model.

In May this year, the premium bicycle manufacturer Rotwild presented the versatile All Mountain R.Q1 e-bike fitted with a compact mid-motor supplied by Brose. The battery is integrated in the supporting framework, enabling the R.Q1 to retain its individual appearance and sporty handling, even in the hybrid version. The mountain bike with Brose drive will be available this fall. At the same time, Brose will start supplying Bulls and Pegasus models (both ZEG). Negotiations are underway with other manufacturers. According to Sven Bernhardt from Brose, Continental is brand-labelling the drives by Brose.

Figure 2: More big ones enter the market – Continental is going to supply electronic units for pedelecs and e-bikes including drives (Photo: Continental)

CAN communication prevails

Like most of its competitors Tranzx (Germany) has implemented a CAN interface in its M25 central motor. Via CAN the motor performance can be steadily monitored and errors can be detected immediately. The Canadian BionX company supplies CAN-connectable units for pedelecs and other LEVs including caddies as well. The company started with I²C-linked units, but switched to CAN as early as 2009 because of its superior robustness and higher reliability. As with most suppliers, the CAN communication is based on a proprietary higher-layer protocol, which is why system designers do not have the choice to select units from different suppliers. Most of the OEMs are fine with this situation: They have no profound electronic background and experience. They are mechanical-driven companies and happy to buy a care-free package from one single supplier. The tradeoff: They are dependent on one supplier. And the suppliers reinforce this development: "The charging of Lithium batteries is so dangerous and electronics is so complex, we provide a safe turnkey solution." Some customers start to wonder if suppliers want to protect the end-user, or if they also want to protect their markets.

Figure 3: Made in Germany – Brose's mid-motor weighs 3,4 kg and generates up to 600 W; this is obtained through use of weight-reduced, yet higher-strength materials (Photo: Brose)

First OEMs start to take the open way, buying from different suppliers and/or developing their own electronic units. Stromer (Switzerland) is such an example, building high-end pedelecs based on the CiA 454 specification. In the high-end market, there are also hobbyists creating their own bicycles out of mechanical components, which are highly standardized and interoperable. They like to do the same with electrical and electronic components. In Internet forums they discuss how to re-engineer the CAN communication (see insert "Hacking CAN messages"). The market-leading suppliers were surprised about the knowledge of those sophisticated end-users.

There is also a trend similar to the car industry: In order to successfully sell vehicles, it is not sufficient to provide a drive system. The customers want to have some other treats as well, e.g. connectivity to their smartphones, an electronic gear, and many more. Bosch has therefore teamed up with Shimano. Users can decide whether they want their gears to shift automatically in line with their cadence (Nu-Vinci, technology from Fallbrook) or speed (Sram), or to select the ideal gear themselves with the electrical assistance of paddles and gear shifting recommendations (Shimano). These built-in gear shifting components promise comfortable pedelec cycling along with a higher level of safety and a harmonious overall design. The electronic solution will be launched on the market in Spring 2015 combined with the above-mentioned Active line and Performance line and the Intuvia on-board computer.

What the solutions have in common is that the components are not only supplied with electricity and operated electronically but that a genuine data interchange takes place via ▷

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Figure 4: Stromer's ST2 provides 500 W of power and 35 Nm torque with a range of up to 150 km (Photo: Stromer)

CAN. This data interchange enables coordinated and optimized gear shifting and shows the gear or cadence that is currently in use on the display. Bosch's Intuvia is an operating computer that can be attached to the handlebar. It has a separate control unit, which is also attached to the handlebar and can be used without taking the hands of.

The integrated Nu-Vinci technology is based on a predefined pedaling cadence preference. The HI-Sync gear system, connected to the e-bike system via the Bosch interface, adjusts the transmission automatically to the preferred cadence, both uphill and on the level. Even when cycling uphill, the system adjusts the gearing automatically. Thanks to HI-Sync the pedaling cadence can be adjusted to between 30 and 80 revolutions per minute via the display and the Bosch Remote. The cyclist specifies gradually how intensively he or she wants to pedal. The seamless N360 hub ensures smooth gear shifting. HI-Sync dispenses with the Nu-Vinci display. The advantage is that the user has all of the important information available at a glance on the display (gear and cadence screen). Alternatively, manual gear shifting with defined settings is available as an option.

The Shimano built-in gear system is suitable for users who shift gears a lot and enjoy shifting gears and like or prefer shifting gears fast. The system is based on manually operated electronic gears in combination with the Japanese company's Di2 Alfine-8 and Alfine-11 or Nexus-8 internal hub gears, all of which can be controlled electronically via a Di2 adapter and CAN. While shifting gear, the motor is throttled briefly, which makes the process gentler and smoother. Di2 is Shimano's proprietary CAN-based solution. The above-mentioned adapter is a bridge/gateway device. It wouldn't be necessary, if CAN communication were standardized.

The Shimano controls have a sporting feel to them. Paddles enable the user to shift gear up or down swiftly. The gear that is in use is shown on the display. For the first time the system incorporates the Bosch gear recommendation, which helps to make better use of the battery's power by means of an arrow on the on-board computer display.

The Sram Dual Drive 3 Pulse is also automatic, but based in this case on speed. The DD3 hub can be combined with a cassette (with up to ten sprockets) and shifts gear automatically in three stages, subject to speed. Users can therefore enjoy the ride, including the acceleration, leaving the system to handle everything else. Even when starting, the right gear is always in place. This version does not require extra control, the system functions on its own. Fewer components on the handlebars ensure an improved overview and a leaner appearance.

Operating pedelec fleets

Operators of pedelec fleets are also in favor of open interfaces. In particular, they are interested in a generic charging infrastructure. The German post administration runs a fleet of more than 6000 pedelecs, which will be increased in the near future. The German DB Bahn railway administration buys pedelecs that their customers can rent. Same situation: two-wheelers from different brands need to be charged at the very same station. In order to overcome this, a standardized interface is required.

Recently, CiA has published the second version of CiA 454. CiA and Energybus members have jointly developed this CANopen profile. Energybus is also a nonprofit association. The official release of the new version took place in the Emtas facilities in Merseburg (Germany). Emtas is one of the active parties who developed the specification. The company also provides a CiA 454 starter-kit and designs a CiA 454 test-tool on demand of the Energybus association. CANopen hardware for CiA 454 devices is available from Pironex. The hardware is used in public charging stations in several German cities (Bremen, Chemnitz, Hanover, and Rostock). The company also offers an Energybus CAN-logger device and other products supporting the CiA 454 specification.

Hannes Neupert from Energybus said: "The idea ▷

Figure 5: The future is open – the PiCAN charger complies with the CiA 454 and the Energybus specifications (Photo: Pironex)

Hacking CAN messages

It is so easy. Just connect a recording device to the CAN-lines and analyze the content of the captured messages. In 2012, the following CAN traffic trace extract was published in an Internet forum:

```
…
33  0  7  0  8  130  146  0  0  0
34  0  7  0  155  0  0  119  15  0
35  0  8  4  0  0  0  0  0  0  0
48  0  8  0  200  39  0  80  5  0  80
64  0  3  16  128  1
33  0  7  0  8  130  146  0  0  0
64  0  3  16  128  1
33  0  7  0  8  130  146  0  0  0
…
```

The highlighted frame uses the CAN-ID 48. The flowing "0" indicates a data frame. The "8" represents the data-length code. The next "0200" was not decoded. But the following "39" was interpreted as battery voltage given as an integer value in volt, and the "080" was taken as 80 percent battery capacity. The following "5" was assumed to be the number of bars to be shown on the instrument. The following value was always constant (0) and the last "80" did not change during the recording. Most of the diagnostic CAN messages in passenger cars have also been decoded. You can reverse-engineer any CAN communication with the support of cheap tools. And the chance that nobody does it is slim – except if you encrypt the data, which also needs to be transmitted securely. But this is costly and the LEV markets are price-sensitive.

for a unified standard came about as part of work being carried out for the electric bike fleet of Deutsche Post AG in the early 2000s. In 2004, the idea of Energybus was introduced for the first time at the LEV Conference in Taipei, and in 2009, the first connector for it was presented. Now, with the significantly extended version 2.0 of this communications protocol the era of industrialization of the Energybus can begin. Several of the over 60 member companies already have Energybus compatible products in their range - and many more are under development."

The CiA 454 protocol doesn't just define communication between charger and battery. In fact, it's also valid for communication within the bike itself. So bike components, starting with the drive, sensors and the power management system and ending with the user display, can all communicate with each other. Furthermore, the protocol also enables software-activated immobilization of bikes via a charge-and-lock cable, in a manner similar to a car immobilizer.

Hannes Neupert reported that Energybus and VDMA have agreed to standardize networked batteries for forklifts based on Energybus: "With this collaboration we are living up to our principles of encouraging innovation and competition in the open market. When it comes to the 'Modular Multi-Use Battery Systems' project that means making the standard accessible to even more sectors and customer groups." Bernhard Hagemann from VDMA added: "This collaboration will actively enable us to bring know-how and experience from Energybus in the field of communication in energy systems to the development of standards for high-performance modular batteries. That is very worthwhile and an important step forwards."

Holger Zeltwanger

Stability of mobile construction machines

The higher construction machines are, the further they can fall. Controlling their stability is not easy, but necessary to ensure their safety. Inclinometers can give early indications of instabilities.

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Many workers have experienced the following changes throughout their career: At the start of a working life, during training, work was undertaken with conventional machine tools – drilling, lathing, milling, welding. Conventional in this case means "controlled by hand". Further development of these working technologies led to NC-controlled machines. These were able to independently and autonomously repeat certain operation steps "semi-automatically". The milling cutter could be taught to move around edges instead of straight through the work piece. Today's crowning glory of this technology is fully automatic CNC technology, which is able to operate more than three axes, and even several axes simultaneously. Radii, arcs, and collision-free movements are possible with the milling cutter.

Mobile equipment such as excavators, cranes, mobile drills, and lifting platforms are still facing this transformation. Leading manufacturers have increasingly begun to automate their machines. This enables working machines to attain increased efficiency. In addition, a new and very important industrial standard has been enforced - ISO 13849. This standard specifies how risks posed by machines are to be evaluated. Risks that endanger man and the environment have to be avoided or extensively reduced by means of sensible and above all safe measures.

Controlling stability is probably the most important topic when it comes to mobile working machines. The taller a system, the more important and difficult guaranteeing its stability becomes. There are varied approaches to solving this, for example measuring the forces that occur and shifting weight to the construction machine's support. These displacements and forces can be placed into relation to the counterweights, if available. Monitoring the inclination angles of booms and lifting equipment can be used as an early indicator of impending instabilities. The extension angle of cables of lifting facilities can be monitored. Accidents often happen when loads are pulled at an angular angle, using ▷

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Operator Interfaces

crane systems that are not designed for this purpose.

Inclinometers from TWK-Elektronik can do more than register specified inclination angles: vehicles can also be leveled safely. The vehicle operator is not merely the driver - he is also responsible for the stable erection of the machine. He bears this responsibility alone, because construction vehicles are usually only manned by one person due to financial reasons. A high degree of automation and corresponding safety is therefore mandatory.

So-called slewing ring encoders can be fitted on the majority of construction machines with a revolving upper structure. These register the angular position of the upper structure versus the under structure in high-resolution using a special, play-free measurement gear. This position determines how far the boom can be extended. High-resolution single-turn rotary encoders with a resolution of up to 22 bits can also be fitted in slip ring assemblies in the center of slewing rings. If this central position is already occupied by a pipe, e.g. for water, oil, or concrete, a slewing ring encoder is used. A special feature of this encoder is the software, which was designed so that the encoder can optionally act as a high-resolution single-turn rotary encoder. Such large, exact, and high-resolution position values can no longer be transmitted by means of a simple analog interface. Many vehicle manufacturers use CANopen to transmit these data volumes.

When using the play-free measurement gear ZRS, no reverse operation occurs when the slewing ring changes direction. An additional benefit of the available position signals is the possible relocation of previous positions and very precise, automatic movement back to these positions. The upper structure position and measurement of the load on the boom can be used to automatically limit the machine's movement range, ensuring that stability remains guaranteed under all circumstances. Limiting operating ranges is also important when for example an excavator is working directly next to a heavily frequented road or a railway line. Automatic shut-off prevents unintentional slewing into the causeway and collision with vehicles.

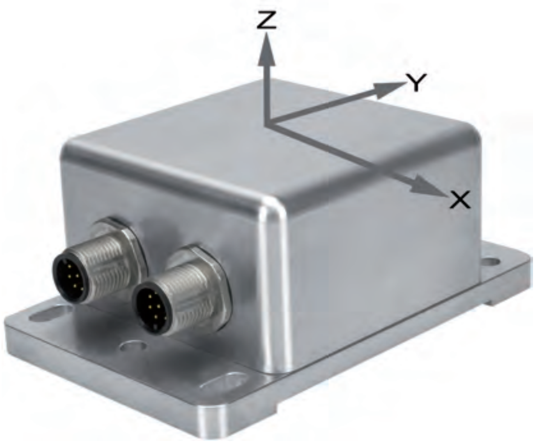


Figure 1: Safe inclinometer, SIL2-certified, with a CANopen-safety interface according to CiA 410 version 1.2

Safe sensors

All TWK sensors for use on safety-relevant assemblies and machines can be or already are certified according to SIL (safety integrity level). The inclinometers and rotary encoders are redundant in design. The position value is available twice in the sensor. SIL-2 does not necessarily require a dual or redundant sensor system design. Neither is it possible to continue working with the second system should one of the two systems fail due to a fault, although a position value is still available from the sensor.

The encoder compares the two position values with each other. If both values are identical, work is continued with just this one value. However, this position value, whose correctness has already been checked, is then transmitted to the control system, once in normal and once in bit-inverted form. In turn, the control system then checks the correctness of both messages.

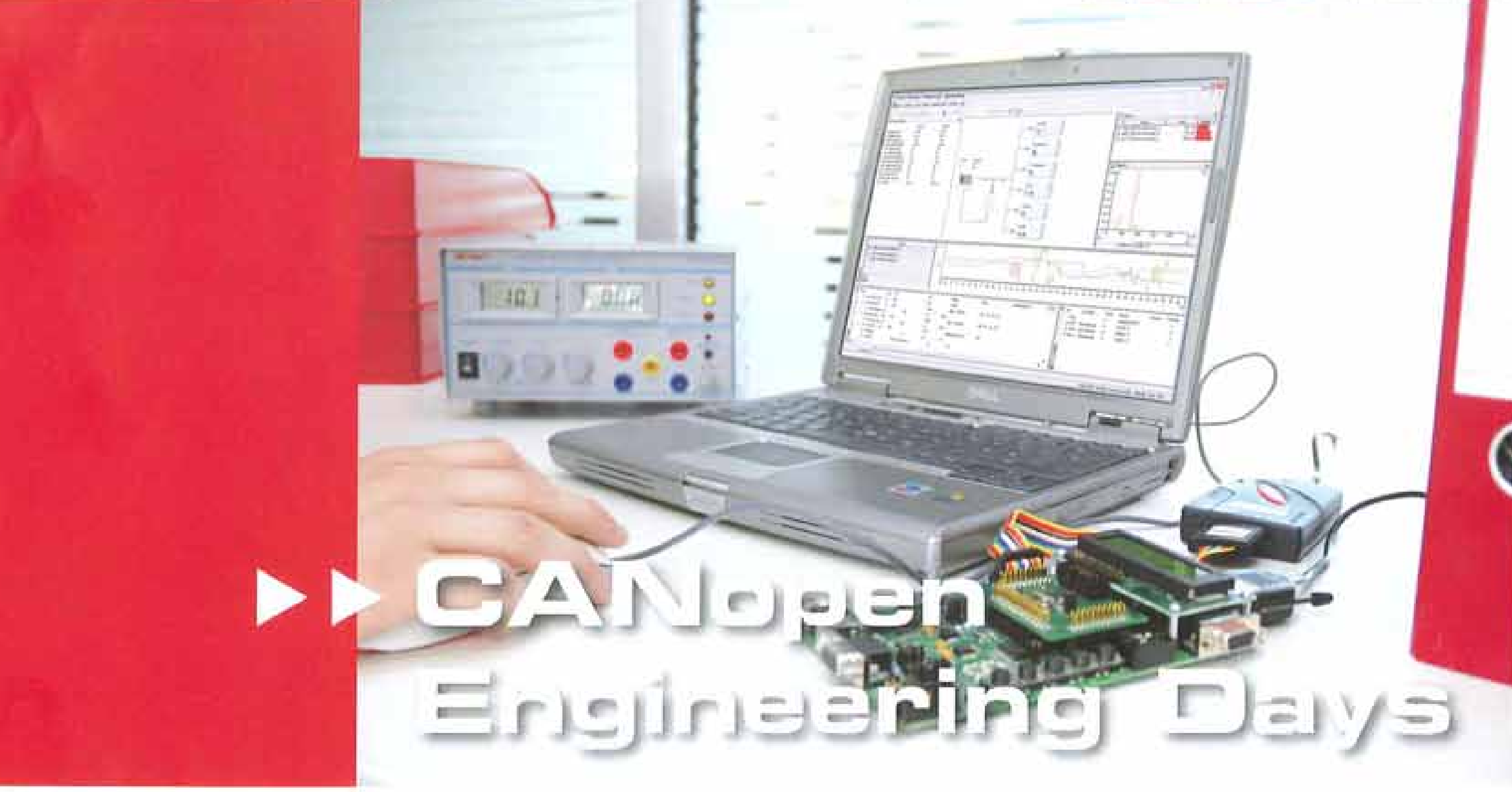
Checksum calculations are integrated at various points in the encoder and also in signal transmission via CANopen-safety in order to perform actual/nominal comparisons and detect errors. If an error or discrepancy occurs in the encoder or during signal transmission, an error message is transmitted to the CANopen control system: the control system automatically triggers an emergency stop or moves to a fail-safe position.

Figure 2: Safe rotary encoder, SIL2-certified, with the CANopen-safety interface according to CiA 406 version 3.0

Mechanical systems

Lateral support plays a major role in the stability of mobile machines, as only single-sided and uneven support is usually possible on construction sites due to space limitations. SWH- and SWF-type linear cable transducers provide information on how far the support has been extended.

So far, it is not generally possible to have cables which are popular in longitudinal measuring technologies with integrated or mounted rotary encoders certified according to SIL. It is very difficult to determine whether a cable mechanism is operating perfectly although the rotary encoder puts out valid (but possibly incorrect) position values and does not report any other errors. The mechanical system can jam or ▷



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10:00 **Offizielle Begrüßung und Vorstellung des Unternehmens**

10:15 **Einführung in das CANopen-Protokoll**

> Einsatzgebiete von CANopen
> Vorstellung der wichtigsten CANopen-Mechanismen:
- Prozess- und Servicedatenkommunikation
- Fehlerüberwachung
- Netzwerk- und Konfigurationsmanagement

11:15 **Live Demo: Vorteile des Werkzeugeinsatzes im CANopen-Entwicklungsumfeld**

> Vorstellung der CANopen Tool-Umgebung
> Logging der Busdaten zur späteren Analyse
> Analyse von CANopen Systemen:
- Effizientes Filtern der Nachrichten
- Übersichtliches Auflisten und Auswerten der Busaktivitäten und -daten
- Grafische Darstellung der Signalwerte zur schnelleren Kommunikationsprüfung
> Stimulation von CANopen Systemen:
- Signalwerte setzen, Signalverläufe definieren, Botschaften senden
- Aussagekräftige Visualisierung mit grafischen Elementen

12:00 **Mittagspause**

13:30 **Live Demo: Über die Simulation zum realen Steuergerät**

> Erstellen einer Gerätebeschreibung basierend auf einer CANopen-konformen EDS-Datei
> Ableiten der Simulation direkt aus der Gerätebeschreibung
> Erweitern eines Knotenmodells um applikationsspezifische Bestandteile
> Umsetzen der simulierten Funktionalität in ein reales Steuergerät

14:45 **Kaffeepause**

15:15 **Live Demo: Effizientes Testen mit flexiblen I/O-Schnittstellenmodulen**

> Effizientes Prüfen der CANopen-Gerätefunktionen und Simulieren potentieller Fehlerfälle mit Hilfe eines HIL-Testsystems
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the cable may be separated due to external mechanical influences. TWK is in dialog with the Technical Inspection Association (TÜV) to implement precisely such a complete measuring system in at least a SIL-2 version and also obtain a yellow SIL badge for the measuring system. In previous applications, it was only possible to have the rotary encoder with cable certified along with the customer's application. In each case, the customers implemented special measures to monitor the mechanical problems specified above.

TWK is able to supply SIL-2-certified rotary encoders for mounting on cables; when a specific rotational speed is exceeded at the encoder shaft, these send an alarm message to the control system. This enables for example the detection of cable tearing. If the measuring cable tears, the cable drum rewinds the remaining cable so quickly that the rotational speed at the shaft is far higher than during normal operation. If the cable jams and the machine sections move towards each other, the cable sags. However, the user or the machine control system is unaware of this. They are merely provided with a stationary rotary encoder position value as if everything was working correctly. The only possibility for detecting this error is to supply the encoder with information concerning the drive unit. Information on whether the drive is moving or stationary would be sufficient. Electric motors or hydraulic cylinders are usually used to execute the machine's movements. If electric motors are used, the rotary encoder can monitor the status of the relay or the contactor; in the case of hydraulic components the valve signal is used.

Therefore if the actuator is activated, the rotary encoder on the cable also receives this signal. If a position value change has not been registered by the encoder after a maximum of 100 ms, the system shuts off or the encoder transmits an alarm message (EMC message) via CANopen. The temporal behavior of the sensor system is dependent on the inertia of the application and must be determined by the manufacturer.

The future belongs to automation

Self-adjusting level control systems are already available in isolated cases. The support facility aligns the upper structure at the push of a button. Crane and recovery vehicles are also equipped with automatic systems that are able to automatically move machine sections, such as e.g. the crane jib on the vehicle's upper structure, to the transportation position and then activate the safety locking system with the aid of position values from various sensors. The vehicle can then only be moved once the fail-safe limit switch on the locking bolt has been pushed and the release signal has been transmitted to the CANopen control system.

For crane systems and lifting platforms, automatic travel in three dimensions – including around obstacles – is still a pipe dream. If corresponding sensor systems and collision controls become available however, new technologies are entirely conceivable. This challenge will have to be met by sensor system and crane system manufacturers in the future. ◄

CAN as trace source

Code and data trace allow a limited view of real-time behavior of embedded systems. Complex systems with more than one core as well as powerful peripherals only become controllable with new trace technologies.

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Reference
[1] The Nexus 5001 Forum Standard for a Global Embedded Processor Debug Interface Version 2.0; http://www.nexus5001.org

On-chip trace has been established as the state-of-the-art technology for debugging and comprehensive system analysis. It is commonly used for testing and performance measurements. Apart from a few exceptions, most microcontroller architectures are available with on-chip trace and all major debug tool vendors promote their support. In general the term 'on-chip trace' means the recording of instruction executions – known as instruction trace – and the recording of data transfers between cores and memories and on the system networks – known as data trace. To meet the customers' requirements for global system observability, major silicon vendors have extended their trace solutions and added signal trace for peripherals like CAN controllers, which are important for debugging, testing, and comprehensive system analysis.

Peripheral trace of Infineon's Aurix

With the Aurix family, Infineon has introduced powerful automotive microcontrollers onto the market during the last year. The combination of three TriCore 1.6 CPUs, a lockstep mechanism and an access permission system makes Aurix suitable for powertrain applications demanding high performance and sophisticated security features. A range of peripherals matches present car drives including hybrid and electrical vehicles.

Debugging and system analysis of such microcontrollers requires sophisticated on-chip debug support and trace. Henceforth for run-time analysis not only program and data trace from cores and busses are needed, but also a bunch of single-bit and multi-bit signals from peripherals have to be taken into account. The challenge was to extend the trace solution to meet these requirements. However with up to a few hundred single-bit signals which want to be part of the trace output, the trace hardware put on the die and not least the trace port come to their limits very quickly. The only way out is to limit the amount of signals coming out of the peripherals according to the actual debug use-case.

For that purpose Infineon has extended the On-Chip Debug System (OCDS) of the Aurix MCUs with a trigger switch (Fig. 1). It allows transfering selected bunches of signals from peripherals to different sinks of the debug system. One of those sinks is the Multi-Core Debug Solution (MCDS) – the trace system of the present Infineon microcontrollers. The vast number of accrued data is preselected by means of multiplexer cascades. Typically sets of 16 or 32 bit signals form so called trigger sets. While the containing signals are fixed for each trigger set, selected trigger ▷

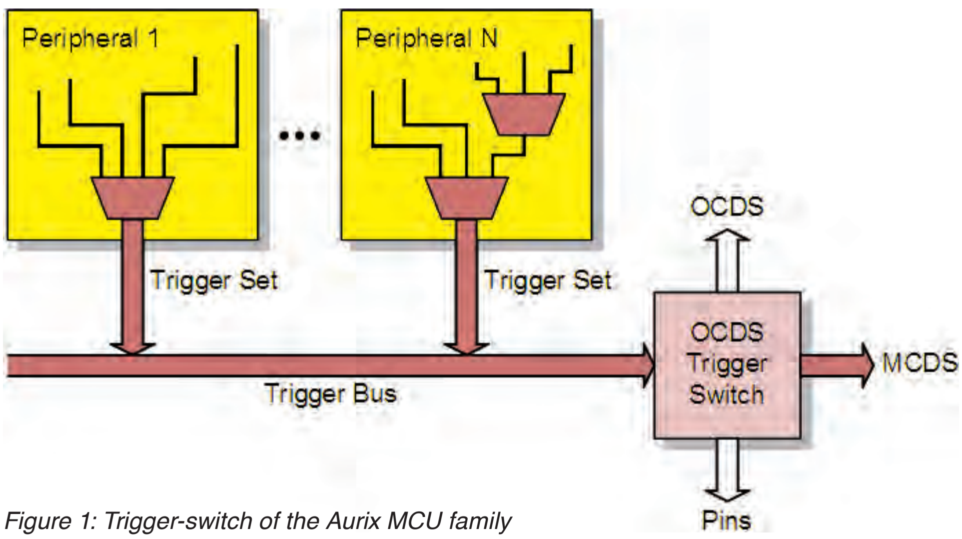

Figure 1: Trigger-switch of the Aurix MCU family

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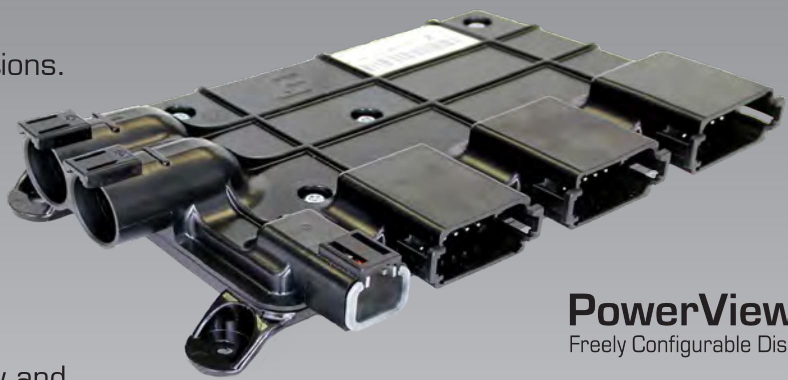

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sets are then transferred by OCDS trigger busses to the internal trace interface. The trace interface itself does not know anything about the origin and content of the trigger sets. It just sees data packets. Therefore, when the captured trace data is decoded, the tool needs to know the actual configuration of the multiplexers and which trigger sets are selected to be part of the trace data.

Peripherals like Flexray, DMA controllers, and CAN of course influence run-time behavior. The integration of their debug signals into the trace system – which is called signal trace in the following – allows reconstructing an almost complete system state via the debug tool and the observation of interactions between CPUs and peripherals.

Managing data floods

We have seen that with the new trace sources – the peripherals – a lot of additional trace data becomes available. However this data flood is hardly controllable. The on-chip debug hardware alone doesn't have the performance to capture all the data and put them off-chip to the debug tool. On chip data are already filtered to keep the required bandwidth for the trace to be reasonable. Of course this is also a matter of analysis efforts. The bigger the information flood the more difficult it is for the tool and in the end for the developer to identify possible functional errors or performance bugs.

A comparatively easy method to configure the multiplexers and filter mechanisms of the Aurix on-chip trigger switch and MCDS is to use the Universal Emulation Configurator (UEC). UEC is part of the Universal Debug Engine (UDE) from PLS and has been in use for powerful on-chip trace units with comprehensive trigger and filter mechanisms for years. The flexible concept behind UECs allows a combination of 'common' program and data trace with the new signal trace. That way a trace task can be created completely with one single tool without the need to separate between on-chip trigger switches and MCDS.

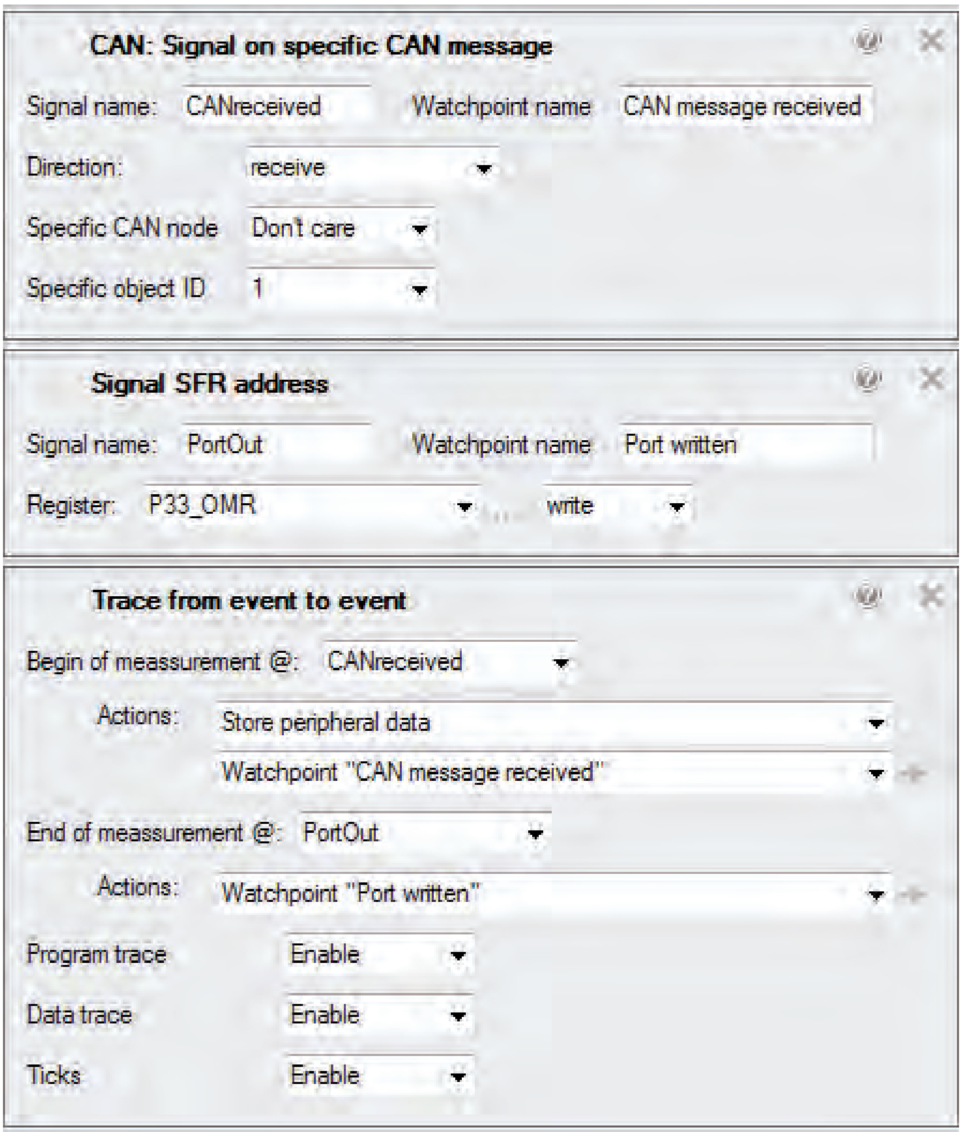

Figure 2: Graphical configuration of a mixed program and signal trace

Of course, the combination of program or data trace and signal trace from peripherals provides benefits if a certain event or interaction between different parts of the controller is of interest. As an example, with trace the time an interrupt service requires from an incoming CAN message to respond with a signal on an external port pin can easily be measured. The on-chip trace recognizes a particular message on the CAN network – it is even possible to filter for the origin and message type – and starts the trace recording. The write access to the port pin is visible to the trace unit as well and can be used as an event to stop the trace. Figure 2 shows the trace task configured with the graphical editor of the Universal Emulation Configurator (UEC). Apart from the time measurement the configuration contains the setup for a complete program and data trace as well. For trace analysis all captured trace data from different trace sources are merged and displayed in a combined view (Fig. 3).

Will signal trace become mainstream?

That is an interesting question. For industrial and automotive applications, signal trace is for sure an important extension to the controller's debug functionality. However you only get these things with some investments in hardware and tools. To keep the hardware costs within limits Infineon pursues their concept of two different controller types: an emulation device with all the additional hardware for high level debugging and trace and a production device to be built in the products only with basic debug support.

Apart from Infineon with its MCDS, another important player in the area of ▷

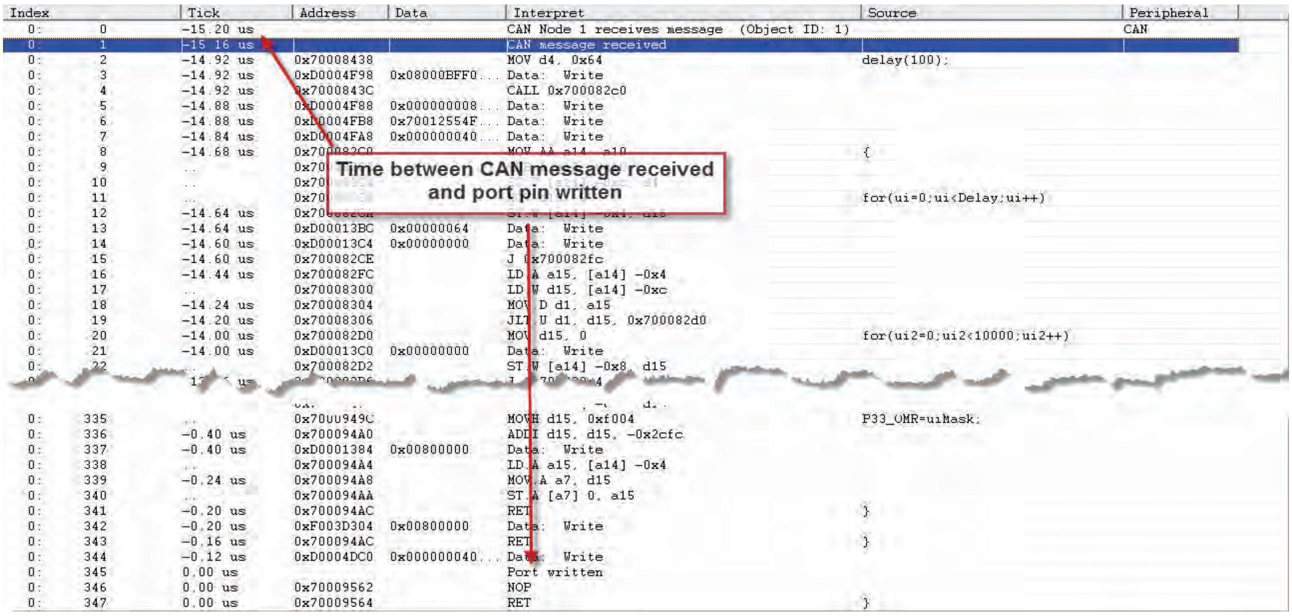

Figure 3: Measurement of latency of an interrupt service triggered from CAN message with program and data trace information as well as signal trace of CAN controller

trace support for industrial and automotive controllers is the Nexus forum [1]. They recognized the need for signal trace too and extended the revision of the Nexus standard 2012 with a new trace type called 'in-circuit trace'. However the CAN network as well as other peripherals are still not attached to the trace system of current Nexus implementations.

For sure the coverage of peripherals by the trace system is an important step forward to fully testable embedded applications. With that, trace becomes more and more an instrument for system analysis of complex and complete systems-on-a-chip and not only for the cores. Now the mission for tool vendors like PLS is to provide software tools like the Universal Emulation Configurator, which allow to fully utilize trace features and to unrestrictedly define tailor-made measurement tasks. ◀

CANopen in the frontline of openness

"Open knowledge is any content, information or data that people are free to use, re-use and redistribute – without any legal, social or technological restriction." [8]

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Open data or open knowledge is one of the most recent IT megatrends [8]. All around the world, data collected by public funding has already been opened to free use and more data is made public all the time. The main problem has been that charging for the use of information collected or produced by public funding has reduced the use of data and related business potential.

All such public data is typically stored in a poorly structured and inaccessible format, often as printable documents, understandable only for human. Opening data means publishing open data in a format that understandable for machines, not changing the status of the data. Quite often usable data is presented in a format that makes data access impractical. Furthermore, individual use of such data may not make sense or provide any big benefits, but combining open data from different sources may provide unexpected benefits.

Control systems are not an exception. There is lots of data freely available and commonly used for various purposes. Data was frequently copied manually and during the design process, which led to a heavy maintenance workload, the use of outdated data, and serious inconsistencies, even between products from the same company. The main reason for this is the fact that data contents are related to service and maintenance and not directly related to the main functions of systems. There are also indirect effects, causing additional delays and workloads with troubleshooting and spare part changes.

A lot of public data is used in CANopen-based distributed control systems. Typically small subsets of data were manually inserted into tools and control applications, which are updated only after serious problems. Another problem is that such data is often hardcoded into applications, so that each update leads to re-testing and re-certification. Updates are in many cases essential, because e.g. new device profiles and SDO abort codes are introduced during development of various standards. New device vendors emerge onto the market, too. Information content often looks constrained and simple, but is continuously updated. Thus, standardized information, storage format, and automatic updates can improve the maintainability of control applications, assembly lines, and service tools.

Open documents

CANopen has always been open by nature. All release status standard documents are freely available for all interested parties, including all draft standard documents, except those which are international or European standards and thus distributed by standardization organizations. Draft standard proposal documents are primarily available for members only, but published for all interested parties as excerpts, instead of full documents. Open standards make CANopen attractive and have increased the size of the whole ecosystem, when compared with competing integration frameworks which are not open and free. Open and free availability guarantees that even small enterprises can bring innovative products into the market with lower costs, unlike by using e.g. J1939, Devicenet, and Profibus.

Common terms and acronyms with their official explanations are available as a freely available document, the CANdictionary. It provides a good starting point for newcomers to learn the basics and practical cross references for experienced people. The original one was written in English but Chinese, Finnish and Russian ▷

Table 1: Generic layout of currently available datasets

Dataset	Column 0	Column 1	Column 2	Column 3
CANopen device and application profiles	CiA profile number	Profile title	-	-
CANopen Vendor-IDs	Vendor-ID	Company name	Department	-
SDO abort codes	Abort code [1] [2]	Description en-us	Description fi	Description sv-se
SI-unit definitions	Unit name	Unit abbreviation	Unit code [3]	Specification number

Table 2: Open datasets currently available from CiA website in machine understandable format

Dataset	URL
CANopen device and application profiles	http://www.can-cia.org/fileadmin/cia/files/cia_profiles.csv
CANopen Vendor-IDs	http://www.can-cia.org/fileadmin/cia/files/Vendor_ID.csv
SDO abort codes	http://www.can-cia.org/fileadmin/cia/files/sdo_aborts_codes.csv
SI-unit definitions	http://www.can-cia.org/fileadmin/cia/files/si_units.csv

translations are also freely available. The CAN Newsletter is a magazine published by CiA, which covers the most recent applications and research results in the area of CAN, CANopen, and other CAN-based system integration frameworks and application layer protocols. A selection of older magazine articles is available on request and from 2012 onwards complete editions can be found online. CiA has organized international CAN-conferences s provides ope some of the conference papers since 1995 and all papers since 2000.

Open design information management

CANopen also defines file formats for describing product identities, device type specific interfaces, and application specific configuration information. Standard file formats enable unambiguous design information process. Standardized information transfers enable efficient utilization of larger ecosystem, e.g. in component supply and subcontracting of both hardware and software components of various sizes. The use of a standardized information transfer also enables tool independence, enabling possibilities to improve the information management tool chain. Furthermore, subcontracting can be easily managed, when all involved companies follow the design information storage standards.

CANopen profile database (CPD) files enable providing application- or SW-component-specific interface management and methods for describing validation criteria for electronic datasheet (EDS) files [5]. Device configuration files (DCF) may also be validated by themselves, because in addition to the current parameter values, they contain all the information that EDS files contain [4]. The name of an EDS file, from which the DCF has been generated, is included in the file. EDS files enable systematic documentation of product capabilities, reducing a need for literal documentation [4] [9]. The number of discussions between suppliers and system integrators is also reduced, because the majority of the essential information is comprehensively described. Standardized device data enables efficient computer-aided designs with minimal manual work, ▷

```
01 import urllib2, os, sys                    # Import required modules
02
03 def saveUrl(srcUrl):
04     # Prepare source URL and path for target file ---------------------------
05     (exeFold, exeName) = os.path.split(sys.argv[0]) # Get local folder
06     (rootUrl, fileName) = os.path.split(srcUrl)     # Get file name from URL
07     tgtPath = os.path.join(exeFold, fileName)       # Build target path
08     # Store URL into target path -------------------------------------------
09     httpResp = urllib2.urlopen(srcUrl)     # Get file from given URL
10     output = open(tgtPath,'wb')            # Open target file
11     output.write(httpResp.read())          # Write into target file
12     output.close()                         # Close the file
13     return tgtPath                         # Return target file path
```

Figure 1: Example code for getting a dataset from given URL and storing it into a local file

increasing the overall efficiency significantly.

There are EDS file editors freely available from different vendors to help create the correct EDS files. EDS file checker is available for free to enable device suppliers to create error free EDS files for their devices. Thanks to those tools, inconsistent EDS files have not been a noticeable problem in recent years. An official conformance test program also verifies the completeness and correctness of EDS files.

Information transfer from design into assembly and service is important. Any erroneous or outdated document may introduce significant failure costs in the assembly line and service. In addition to delayed operation, documentation failures may introduce additional component consumption and additional time needed for disassembling assembled faulty components. Therefore, the use of standard DCF files as a transfer format from design to assembly and service [4] provides a significant increase in quality and performance.

In addition to tool independence, EDS and DCF files provide an integrated mechanism for integration of various design tools [6]. Such a mechanism enables the flexible utilization of generic and target device specific tools without increasing the required workload during the design process.

Open constant data

Certain constant data is needed for various purposes during system development. Device profiles, vendor-IDs and SDO abort codes are needed in design, assembly and service tools as well as in the control system GUI devices. SI-units are mostly needed for signal scaling in the application development and for signal scaling and visualization in GUI devices. Analysis tools get unit information from communication databases, where the unit information currently needs to be added manually. Unit information is not directly supported by EDS and DCF files, but in case of many device profiles, unit information may be combined from values of other objects [10].

Traditionally constant data is manually inserted separately in each project, which results in inconsistent information contents and an extensive decrease in both quality and efficiency. While adding the information seems to be simple, one should remember that all information is continuously updated and updates should be available for each purpose with a minimum effort.

CANopen data is available in a comma-separated values (CSV) format, where a semicolon is used as a column separator. The use of columns is included in Table 1. Another format may not provide significant benefits, because the data currently describes certain enumerations only. The first row always contains the column titles and further rows contain the actual data. Additional translations may be provided for SDO abort codes and are added as further columns. The same language coding scheme, which is used in XDD and XDC files, is used for column titles of abort code descriptions [7].

In addition to the SI-unit descriptions, unit prefixes have been defined [3]. They don't need to be published as a table, because prefix factor values are defined as 10[prefix value] and literal prefixes are the same, independent of the language.

Getting open constant data

Currently supported datasets and locations are listed in Table 1. Vendor-IDs and supported profiles have been provided by CAN in Automation (CiA) since 2008. SDO abort codes and SI-unit descriptions have been collected and provided with Finnish and Swedish translations by the CANopen Competence Center Finland. Further information was published to enable application developers to keep the generic constant data up-to-date, without suffering from repetitive manual work.

Two generic sample code examples are provided to give everybody an easy start for getting the data. Python was selected as an example language, because it is a productive language and available for free. For more details, readers are advised to refer to the Python documentation. The first example is the function saveUrl in Figure 1, which takes an URL of a dataset as an argument, loads the given URL into a local file and returns the full path of the file. By default, in lines 4 to 7, the target path is determined to have the original filename from the given URL and same folder with the loading code module. Lines 9 to 12 load the given URL and store the contents into a file with a previously generated path.

After getting the local copies of the data, it should be translated into an usable format. The example function ▷

```
import csv        # Import CSV module

def getCsv(srcPth):
    d = {}        # Prepare result dictionary
    flds = []     # Prepare field array
    # Parse column names ----------------------------------------------------
    dictReader = csv.DictReader(open(srcPth, 'rbU'), fieldnames = flds,
        delimiter = ';', quoting=csv.QUOTE_NONE) # Read CSV
    hdrs = dictReader.next()           # Read first row
    for dd in hdrs:                    # Get result
        nrOfCol = len(hdrs[dd])        # Get number of columns
        flds = hdrs[dd]                # Get column names
        for i in range(0, nrOfCol):    # Loop through columns
            d[hdrs[dd][i]] = []        # Use column items for dict keys
    # Parse column data -----------------------------------------------------
    dictReader = csv.DictReader(open(srcPth, 'rbU'), fieldnames = flds,
        delimiter = ';', quoting=csv.QUOTE_NONE) # Read CSV
    hdrs = dictReader.next()           # Read first row to move read point
    for row in dictReader:             # Read rows
        for key in row:
            if key in flds:            # Take only existing fields
                d[key].append(row[key])
    return d                           # Return as dictionary
```

Figure 2: Example code to read a CSV-format dataset into a dictionary

getCsv in Figure 2 reads any CSV format file by utilizing a standard csv library and returns the contents as a Python dictionary. The CSV file is read and parsed into rows and columns in lines 7 to 8. The first line is picked at line 9 and column names are extracted into an array in lines 11 to 14. Source data may consist of any number of columns and the column names are read from the file itself. Therefore the actual values need to be read in another phase, in lines 16 to 17 by using previously read column names as dictionary keys. The read pointer is moved into the second row in line 18 in order to get only the actual data from the file. Lines 19 to 22 read the data into the dictionary. The resulting dictionary contains columns named according to the first line of the CSV file. There are array items for each row.

Summary

Common, public constant data has been available since the beginning of CANopen, but first in a format only readable by humans. The main problem has been that the data is continuously updated. Especially vendor-IDs but also device profiles and sometimes new abort codes and units have been added. Automated updates are saving time and effort required for updates and removing typing and translation errors.

A uniform presentation of data can be achieved by adopting an automated use of open data. As a consequence, system operators and service personnel will not be confused by differently written vendor names, SDO abort codes with inconsistent wordings, differently named device profiles or units. Design engineers need not spend several hours for regular updates of such data. Thus, all people involved can focus on more productive work.

Future plans include the opening of at least error register flags, object dictionary command keywords, NMT-states and -commands in order to provide uniform wordings in several languages. Currently, information contents of e.g. error register flags to the service personnel have been limited, because of the non-uniform wording. Furthermore, official short descriptions are not currently available for object dictionary command keywords.

At the time of writing, Ixxat and TKE offer products supporting automatic updates directly from CiA website. If there are others, those companies are invited to provide information, for example in the CANopen Linked-In group. Readers are also invited to provide proposals for new datasets to be opened and possible improvements for currentdatasets.Let'simprove the CANopen world together! ◀

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CAN FD: Measuring and reprogramming

The complexity of the CAN FD technology is equivalent to the regular CAN network but it offers a significantly increased bandwidth. It is therefore an alternative to Flexray or Ethernet networks.

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Links
www.vector.com

Literature:
CAN-FD specification V1.0, Robert Bosch GmbH

CAN with a flexible data rate (CAN FD) is a technological evolution of the CAN network. It provides more bandwidth than CAN with less complexity than Flexray. The network specialists at Vector investigated two typical applications, measurement of ECU internal signals via XCP and ECU reprogramming, using the CAN FD system.

ECU measurement with XCP on CAN FD

In ECU development, the measurement and calibration of multiple signals and parameters for open and closed loop control algorithms represents an important calibration use case. ECU developers prefer to use the XCP (Universal Measurement and Calibration Protocol) measurement and calibration protocol that has been standardized by ASAM e.V. In the current protocol version 1.2, CAN FD is introduced as a new XCP transport layer. XCP enables the utilization of measurement and calibration tools such as Vector's CANape (Figure 1) to modify parameters during real-time operation and measure the altered behavior of the ECU. Considering a CAN system the bandwidth of the transmission medium may quickly become exhausted, depending on the number of signals to be monitored. XCP on CAN FD significantly extends the capabilities with up to 64 bytes of payload and data rates of at least 5 Mbit/s in the data phase.

XCP on CAN FD data throughput

To estimate the maximum available data throughput of XCP over CAN respective to CAN FD, the frame size versus the available payload within a frame has been investigated for a measurement of multiple ECU signals. The data throughput calculations are based on the assumption of 100 % bus load. The actual size of the frame fields for CAN and CAN FD are shown in Table 1 and Table 2. However, frame sizes cannot be predicted precisely for either CAN or CAN FD. To assure synchronization of bus nodes to signal edges, in dependence of its content an a-priori unknown amount of additional stuff bits is in- ▷

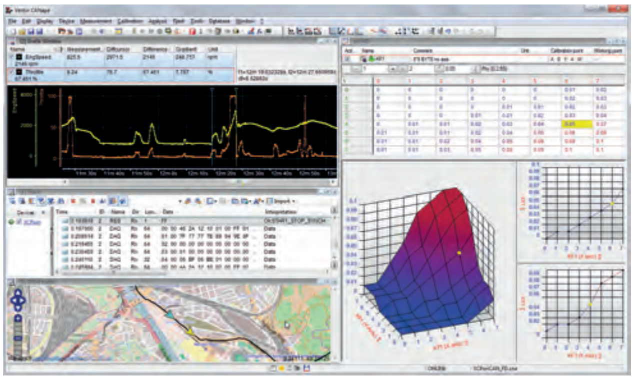

Figure 1: Measurement over XCP on CAN FD with CANape

serted into the frame. To model the stuff bit dependent frame size variation, a best and worst case scenario has been analyzed.

The results of data throughput calculations are graphically represented as a sector (Figure 2, Table 3), where a frame may reside in dependent of its actual contents. To verify the theoretical calculation, a realistic measurement reflecting a practical measurement use case was processed based on a simulation environment. At the laboratory setup – which consists of CANape measurement and calibration software, suitable interface hardware and a PC-based ECU emulation – the time of flight between the in- and output of the CAN/CAN FD driver was measured in both directions. The experimentally measured values greatly meet the mathematical prediction (Figure 2, Table 5) and hence verify the modeling of the available data throughput. Comparing the acquired measurement data needed for a transmission using CAN versus CAN FD, the data throughput of CAN FD has been found to be increased by factor 1.3 up to 5.4 depending on the system's configuration (Table 4).

Above its already improved bandwidth, XCP over CAN FD possesses further potential for improvement. Due to the equivalent physical communication basis of CAN and CAN FD, it is likely that the communication paths of existing ECU software will still be limited to an eight-byte data transmission after migrating to CAN FD. In this case XCP can only benefit from the higher data transmission rate but cannot utilize the full 64 bytes of payload available in CAN FD frames. To optimize the data transmission rate, the payload of small XCP packets could be concatenated as a large CAN FD frame (Figure 3). Vector is currently working on a proposal that enables packet concatenation for XCP over CAN FD in a future XCP specification.

Flash programming

(Re-) programming of flash memory is the second use case in which significant improvements are expected through the utilization of

Table 1: Structure of a CAN frame

Name	Size [Bit]
Start of Frame	1
Arbitration Field	12
Control Field	6
Data Field	≤ 64
CRC Field	15
Acknowledge Field	2
End of Frame	10

Table 2: Structure of a CAN FD frame

Name	Size [Bit]
Start of Frame	1
Arbitration Field	12
Control Filed (1^{st} part)	4
Control Field (2^{nd} part)	5
Data Field*	≤ 512
CRC Field*	18 / 22
Ackknowledge Field	2
End of Frame	10

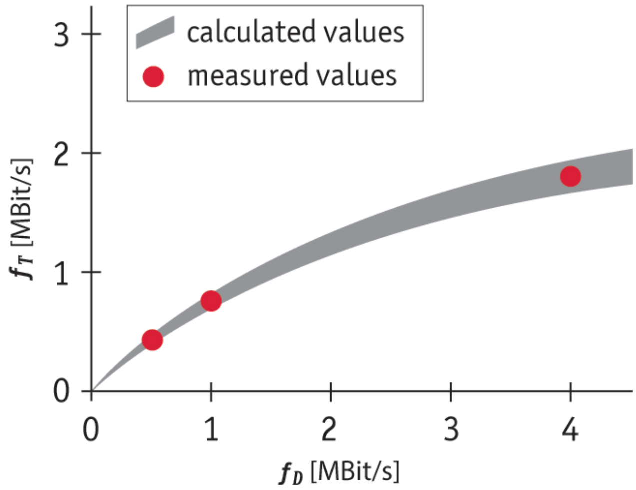

Figure 2: Measured and calculated CAN FD data throughput in ECU measurement

fast network protocols. In the three flash phases "delete", "download/program" and "verify", the download time is a key factor in conventional CAN systems, that can be accelerated by faster bus systems such as Flexray, Ethernet and CAN FD.

Regardless of the transmission protocol, it makes sense to use additional optimization strategies for downloading, such as data compression and pipelined programming. Although compression by an LZSS (Lempel-Ziv-Storer-Szymanski) algorithm reduces the volume of data to be transmitted, its efficiency is highly dependent on the data structure, and data extraction in the ECU generates additional CPU load that need to be taken into account. Pipelined programming, on the other hand, represents a type of parallelization: while a data segment is still being written in the ECU, transmission of the next segment is already started. Therefore, the potential performance gain from this method is the greatest when programming times are shorter than data transmission times.

Flexray offers a transmission rate of 10 Mbit/s, but it is not fully available for (re-) programming. In the periodic communication sequence of the time-triggered protocol, all PDUs (Protocol Data Unit) are predefined in fixed slots. If many slots are reserved for diagnostic service requests such as for download, this reduces bandwidth for the useful data. Realistic configurations provide for 4 PDUs to 8 PDUs with 42 bytes to 255 bytes each per cycle for diagnose services. Vector engineers have measured download rates of 40 to 60 kB/s when pipelined programming is used.

Table 3: Calculated data throughputs of data measurement with XCP on CAN FD (fA=500 kbit/s)

f_D [kBit/s]	f_T [kBit/s] Best Case	f_T [kBit/s] Worst Case
500	407	341
1000	753	635
4000	2130	1825

Table 4: Comparison of measured data throughputs of data measurement with XCP on CAN and CAN FD

	Measured CAN	Measured CAN FD	Factor
Min.	294 kBit/s	380 kBit/s	1.3
Max.	318 kBit/s	1712 kBit/s	5.4

Table 5: Measured data throughputs of a data measurement with XCP on CAN FD (fA=500 kbit/s).

f_D [kBit/s]	f_T [kBit/s]
500	401 ± 21
1000	724 ± 46
4000	1884 ± 172

Ethernet with Diagnostics over IP (DoIP) per ISO 13400-2 is also well-suited for fast reprogramming of ECUs. In testing 100 Mbit Ethernet and a typical microcontroller with a pure flash write rate of 180 kB/s, results were largely a function of the buffer size of the Transfer-Data service. A 16 KiB buffer enables throughput of around 150 kB/s, which is already near the limit of the flash memory used in the test.

Reprogramming via CAN FD

Since semiconductor manufacturers do not offer any microcontrollers that provide CAN FD support yet, network specialists at Vector used a microcontroller in which the CAN FD controller was implemented in an FPGA for their CAN FD measurements. The software stack on the board consists of a standard Vector UDS bootloader. The ISO 15765-2 transport layer and CAN driver were extended for support of CAN FD. To permit a quick test setup process for download testing, the CANoe simulation and testing tool was used, because the tool already offers CAN FD support. This software uses an external DLL which provides the flash programming procedure and transport layer functions. In the future, the Vector vFlash flash tool will become available for CAN FD.

With the transport layer that is used, the theoretically attainable transmission rate in flashing over CAN FD is 270 kB/s to 370 kB/s at 4 Mbit/s in the CAN FD data phase. However, real measured values lie well below this (Figure 4). Surprisingly, the compression and pipelining optimization strategies were counterproductive for CAN FD in the test environment that was used. The reason is that, in the laboratory setup used, the programming time for the internal flash memory became the limiting factor in the flashing process. So this made optimizations to the download phase ineffective. However, further tests with more powerful CPUs are needed to arrive at more general conclusions about data throughput and the effectiveness of optimizations. A key finding of the measurements is that CAN FD delivers a significantly higher data throughput than CAN (Figure 4), and the effort required for migration is negligible.

Summary and outlook

Overall, it is still difficult to arrive at an objective comparison of the serial bus systems CAN FD, Flexray and Ethernet due to their different microcontrollers and constraints, but certain tendencies can be clearly discerned. In the case of Flexray, high download ▷

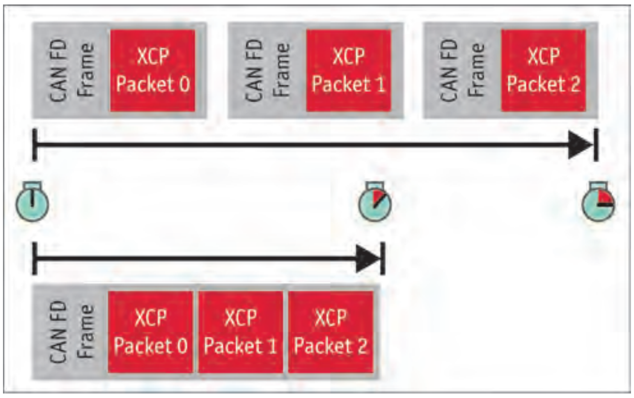

Figure 3: Faster data transmission by multiple XCP packets combined in one CAN FD frame

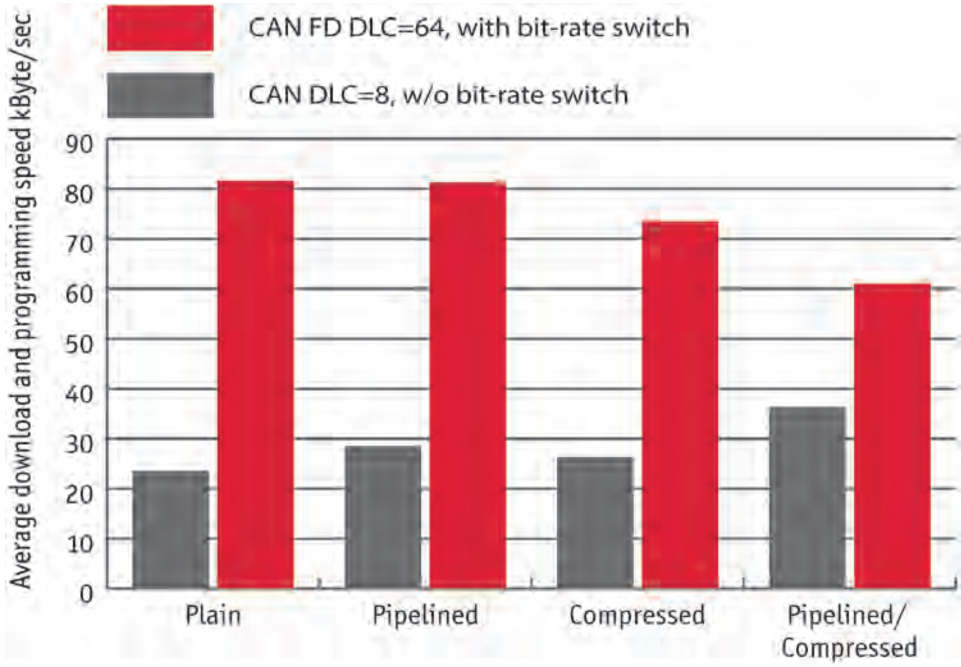

Figure 4: Comparison of download and programming times with CAN and CAN FD

speeds and high performance for the real time data payload are not both achievable at the same time. 100 Mbit Ethernet delivers the fastest transmission rates, but it requires complex software configuration, and its hardware costs are higher than for CAN FD. CAN FD appears to be the most balanced solution, it offers high data rates and the potential for further improvement at moderate costs. In addition, it is relatively easy to migrate to the improved CAN, because of the close similarities between CAN and CAN FD. Both protocols are based on the same physical layer, and this enables reuse of transceivers, wiring and bus topologies. Since the communication principle has not changed either, existing know-how can still be applied. The modifications to affected software layers in calibration and reprogramming that need to be made are relatively minor.

CAN FD enables significant throughput gains in both measurement and reprogramming of ECUs. In (re-) programming, this shifts the bottleneck more to the flash memory. Further development to shorten the memory access times of the MCUs that are used promise additional performance gains. Efforts by Vector to extend the XCP specifications to include packet concatenation with CAN FD also offer the potential for increasing performance of the new protocol that is still untapped. ◄

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- CAN FD bit rates for the data field up to **12 Mbit/s**
- CAN bit rates from 40 kbit/s up to 1 Mbit/s
- Measurement of the bus load including error and overload frames on the physical bus
- Induced error generation for incoming and outgoing messages
- Switchable CAN termination and 5-Volt supply
- Each CAN channel is separately opto-decoupled against USB and LIN up to 500 V
- Extended operating temperature range from -40 to 85 °C

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