History and trends:

CAN goes on (and under) the sea

CAN networks are used in maritime electronics since a long time. There are different standardized applications based on CANopen and J1939 (known as NMEA 2000). Currently, CiA started to specify a dual-mode redundancy concept suitable for all three CAN protocol generations.

(Source: Adobe Stock)

Already, mid of the 90ties, MTU (Germany) reported on the 2nd international CAN Conference (iCC) in London about CAN networking in ship automation systems. Dr. Olaf Schnelle presented the MCS-5 decentralized automation system, which was on duty for about 20 years. In the meantime, it is substituted by the Ethernet-based MCS-6 monitoring and control system. In midterm, all MCS-5 systems will be converted to the MCS-6 controllers. MTU's engine control system (ECS) is still connected to the MCS-6 host controller by means of a CAN interface and discrete I/O lines. The CAN interface is redundant as required in marine applications.

Another early adopter of CAN networking in maritime electronics was Kongsberg (Norway). Jointly with Ixxat (now part of HMS networks, Sweden), the Norwegian company developed ship automation systems based on CANopen. Prof. Dr. Konrad Etschberger (Ixxat) presented it on the iCC 2000. This technical solution went into the CiA 307 specification for electronics in ships and vessels. In the meantime, the document was withdrawn. The significant parts of the CiA 307 document, especially the CANopen redundancy, has been moved into the CiA 302-6 document not more dedicated and limited to marine applications. A typical product, implementing the profile, is the segment control unit (SCU) by Kongsberg, which can manage multiple CANopen network segments. Optionally, the SCU provides an Ethernet-Powerlink interface running a CANopen-based application layer. The K-Chief 600 propulsion control system is another CAN-connected product by the Norwegian container vessel supplier.

The Finnish company Wärtsilä is a manufacturer of marine engines with embedded CAN communication. As an example, the Wärtsilä 46F medium-speed marine engines with power outputs up to 11250 kW are available in 6- cylinder to 9-cylinder in-line configurations. For condition-based maintenance, the engine provides continuous temperature monitoring of the bearings and the exhaust gas as well as real-time data monitoring of the engine performance. The 46F is equipped with a scalable embedded control system based on five hardware modules controlling engine safety functions, instrumentation, speed control, overall engine functionality, and the electronic fuel injection. The architecture is based on CAN for communication between the modules and Ethernet connection to the external automation systems. The system also internally implements redundancy on selected systems and components. Recently, Wärtsilä introduced the 46TS-DF engine, which is designed with a focus on efficiency, environmental performance, and fuel flexibility. In gas fuel mode, the engine has the highest efficiency thus far achieved in the medium-speed engine market, said the manufacturer.

Dual-mode redundancy also for CAN FD and CAN XL

The CANopen redundancy concept specified in CiA 307 respectively CiA 302-6 is not suitable for CAN FD and CAN XL. Therefore, Kongsberg and Microcontrol started to develop a generic dual-mode redundancy solution for CAN-based interfaces independent of the used CAN data link layer protocol. It should suit Classical CAN, CAN FD, and CAN XL. It is currently under development in the CiA Interest Group high availability. This dual-mode redundancy approach is based on two independent CAN interfaces each comprising a CAN controller and a CAN high-speed transceiver. There is also a finite state automaton specified, which manages the selection and eventually the swapping of the active and the passive interface. The data frames are always transmitted on both segments, but on the receiving side there is only one line active.

For redundant use, some connectors with their recommended pinning are given in the CiA 106 Technical Report. This document dedicated for all CAN-based higher-layer protocols and CAN generations derives from the CiA 303-1 connector recommendations formerly specified for use with CANopen.

NMEA 2000: The J1939-based network for navigation

End of the 90ties, the US-based National Marine Electronics Association (NMEA) developed the successor of the 4,8-kbit/s NMEA 0183 serial communication link. This approach was based on the CAN lower layers and the ▷

Figure 1: The NMEA 2000 application profile for maritime electronics is especially used in navigation systems (Source: Adobe Stock)

J1939 application layer i.e. using Classical CAN communication with 29-bit CAN-Identifiers. It was named NMEA 2000 and internationally standardized in IEC 61162-3 running at 250 kbit/s. The multi-drop network is not completely interoperable with all features of the J1939 specifications, but can co-exist in J1939 networks. The cabling is similar to Devicenet specifications. The fast packet transport protocol is limited to 223 byte and does not require a segment confirmation. CAN in Automation (CiA) is observing the standardization activities of the NMEA association. According to the organization, there are no plans to migrate to CAN FD or CAN XL.

The CAN-based higher-layer protocol and application profile for maritime electronics is especially used in navigation systems. NMEA 2000 products need to be certified by the non-profit association. Examples of NMEA 2000 devices include GPS receivers, navigation and engine instruments, nautical chart plotters, wind instruments as well as depth sounders. Some companies such as Furuno, Raymarine, and Simrad offer other connectors as specified in NMEA 2000. They sell their products not under the brand NMEA 2000, but use the NMEA 2000 parameter groups (PG).

NMEA 2000 product suppliers

Of course, there are several providers of CAN-supporting hardware, software, interfaces, and services for the marine industry. The CiA member company Wärtsilä Lyngso Marine (former Søren T. Lyngsø in Denmark) belongs to the Wärtsilä group and develops electronics for the marine applications. The product range includes automation devices as well as communication and navigation systems. CANopen, J1939, and NMEA 2000 higher-layer protocols can be supported.

Warwick Control Technologies (UK) provides the J1939-based protocol stack kit supporting NMEA 2000. It comprises the protocol stack in C source-code, an STM32 development board, an NMEA-certified reference design CAN driver for STM32 micro-controllers, the X-Analyser tool, and the Leaf Light USB dongle by Kvaser. The C source-code incorporates such J1939 features as address claim, fast packet protocol, BAM (broadcast announce message), connection management data transfer, etc. The X-Analyser analysis and simulation tool supports NMEA 2000, J1939, CANopen, and CAN FD. For J1939, it allows to view parameter group number (PGN) packets, compare them to the raw CAN data, and to decode the packets into fields and signals. It also looks for harness/connector problems in the CAN signal. The analyzer supports all Kvaser CAN interfaces, as well as the Picoscope 2206b by Pyco Technology.

Compass system for demanding environments

The Standard 22 NX gyro compass system provides heading information for safe navigation (Source: Raytheon Anschütz)

Raytheon Anschütz (Germany) developed the modular Standard 22 NX gyro compass system providing heading information for safe navigation. As it needs to operate accurately and reliably in stressing environmental conditions, the company undergone the device to a rigorous testing. In addition to the company's approval test standards, the pre-production units were evaluated for twelve months at the company's production facilities in Kiel, Germany and on a ferry in the Baltic Sea.

The system includes NMEA 2000 interfaces for connection of additional heading receivers or of the bridge alert management (BAM). It also enables a direct connection of rate-of-turn indicators. Two Ethernet interfaces are offered as well. The integrated ship-board webserver simplifies the system's installation. Interfaces are organized by selecting NMEA 2000 telegrams, bit rates, and update rates. Also configurations can be downloaded and uploaded via the webserver. This enables configuration times of few minutes. The system's gyro compass accessories include heading distribution units, operator units, and repeater compasses. It can be integrated into the company's existing Standard 22 and Standard 30 MF systems, and added to the redundant CAN networks using six wires.

Figure 2: The wireless CAN bridge by Kvaser enables CAN communication in situations where wired CAN connection is challenging e.g. in marine applications (Source: Kvaser)

Beside of CAN interfaces, further hardware, and tools, Kvaser offers the recent configuration-free Kvaser Air Bridge Light HS M12. The wireless CAN bridge with ▷

dust and water-resistant M12 connectors can replace CAN cables in marine and other extreme environments. Comprising a pre-configured pair of wireless units with integrated antennas and rugged housings, the bridge exchanges raw CAN data between two networks when a wired CAN connection is challenging. The transmission range is up to 70 m, with a maximum data rate of 1 200 messages per second and a packet latency of 4,8 ms. Although this model incorporates two 5-pin M12 connectors with NMEA 2000 compatible pinning, the bridge is not an NMEA 2000-certified device.

The MLI-E 12/1200 Lithium-Ion battery from Mastervolt comes in a water proof plastic case, recharges in less than an hour, and deep-cycles 5000 times, which is up to 10 times longer than for lead-acid batteries. For integration in mobile and maritime power systems, NMEA 2000 and CANopen protocols are supported. The battery is protected against overcharging, deep discharging, and overheating and comes with an integrated electronic safety switch. The MLI-E is provided with integrated battery monitoring, including information about state of charge and time remaining.

Figure 3: For integration in maritime power systems the NMEA 2000 protocol is supported (Source: Mastervolt)

Connecting measurement equipment under the sea

Figure 4: The off-shore platforms for oil production are linked to sub-sea CANopen networks comprising redundant controllers, different sensors, valves, and other equipment (Source: Adobe Stock)

CAN networks are used not only above the water surface. Under the sea, diverse sub-sea measurement equipment and control systems can be interconnected via CAN. For instance, the off-shore platforms for oil production are linked to sub-sea trees (nicknamed Christmas trees) comprising redundant controllers, different sensors, valves, and other equipment. These devices are located on the ocean ground in depths up to several hundreds of meters and are connected by means of CANopen networks. Such devices (also known as SIIS level-2 devices) comply to the CiA 443 CANopen profile, which was developed and ▷

Solar boat project

CAN-controlled hydrofoils allow the SR02 boat to get elevated over the water line, thus reducing the drag forces and the energy consumption (Source: Kvaser)

Since 2015, cross-degree engineering students at Lisbon's Instituto Superior Técnico work together on the development of solar-powered boats. The main purpose of the Técnico Solar Boat (TSB) project is to participate in worldwide engineering competitions. In the Monaco Solar & Energy Boat Challenge (biggest in the world), the SR02 boat developed by the students took the 2nd place on the podium (A-class) in 2019. The team competed with 34 teams from 14 different nationalities. In a remote competition in 2020, the students won the innovation prize among the eleven participating teams. As there was no further competition in Monaco, the university started its own Odisseia TSB event, traveling along the Portugal coast, doing some crossings, and testing the boat's capabilities.

The SR02 boat implements a CAN-based system to control the motors, the hydrofoils system, and to check the state of temperatures, voltages, currents, etc. The hydrofoils allow the boat to get elevated over the water line, which reduces the drag forces and the energy consumption. While development, the Kvaser Canking software was used to monitor and analyze the CAN traffic. The Kvaser Memorator Pro 2xHS v2 interface and Kvaser Database Editor helped to log data from the vessel for further analysis. A self-developed Matlab App allowed to extract required data from a .mat file generated with the Kvaser Memorator configuration tool. This enabled the team to evaluate the data from a desired period of time, to see the variables' change along a travelled distance, or to check the boat position for each instant of time.

The students are currently developing their third solar-powered boat SR03, and finishing its first hydrogen-powered boat São Miguel 01 (SM01), which will also use the Memorator Pro 2xHS v2 CAN interface with dedicated software.

is maintained by CiA in cooperation with the SIIS (Subsea Instrumentation Interface Standardization) group. The SIIS level-1 specifies discrete analog interfaces and the SIIS level-3 defines Ethernet interfaces.

The devices are controlled by an application manager, which is not specified in the CiA 443. Often, two manager entities are integrated into the network providing NMT (network management) “flying” manager functionality as specified in CiA 302-2. The virtual device concept of the CiA 443 profile enables a SIIS level-2 device to provide a sub-layered network or serial links. Thus, it acts as a gateway and provides proxies for the connected functional elements (e.g. different sensors). This means, SIIS level-1 devices can be easily integrated into SIIS level-2 networks. Of course, the sub-layered network may also comply with CiA 443. Two different physical layers are specified. Besides the low-power, fault-tolerant transceivers (compliant to ISO 11898-3) optionally high-speed transceivers (compliant to ISO 11898-2) are allowed. The default bit rate is 50 kbit/s and the bit-rate of 125 kbit/s is required as well. The SIIS group organizes plugfests, where the interoperability of CiA 443 compliant devices can be proven.

CAN in underwater vehicles

Figure 5: The 3,5-m-long AUV weighs less than 700 kg and provides a slim CAN architecture (Source: Fraunhofer IOSB-AST)

There is a growing demand for underwater vehicles. Several thousand meters below the surface, oil companies are prospecting for new deposits and deep-sea mining companies are looking for valuable mineral resources. The thousands of kilometers of pipelines and submarine cables need a regular maintenance. Additionally, the marine scientists would like to be able to use robust underwater exploration vehicles to survey large areas of the ocean floor.

To meet these demands, researchers at the Fraunhofer Institute for Optronics, System Technologies and Image Exploitation IOSB in Ilmenau and Karlsruhe have developed an autonomous underwater vehicle (AUV) using internal CAN communication. The development of the vehicle, which should be manufactured in large numbers, was finished in 2016. The companies have been using AUVs in deep-sea exploration missions for many years. Formerly used vehicles have been custom-built and expensive. They have had complex structures, which made them difficult to access by the vessel crew, e.g. when replacing the batteries. It took also more than one hour to read the large observation data files from the UAV’s on-board processor. Many of these vehicles were also so heavy, so that only specially trained operators could place them into the water using the ship’s winch.

The IOSB’s AUV called Dedave (Deep Diving AUV for Exploration) and resembling on a space shuttle, overcame these problems. It is capable of diving to depths of 6000 m. The embedded CAN system reduces cabling complexity. It consists of a slim cable to which all control devices, electric motors, new modules, sensors, or test devices can be connected. Batteries and data storage devices are held in place by a simple latch mechanism, allowing them to be removed with a minimum of effort. There is also no need to download data from the processor. Because of the weight (less than 700 kg) and size (3,5 m long), four Dedave AUVs can found place in one standard shipping container. Usually there is only enough room for one vehicle. Therefore, larger than usual areas of ocean can be surveyed in less time. The additional carrying space (ca. 1 m in length) is sufficient for installing further different sensors for capturing ocean floor survey data.

Figure 6: Replica of the Avro Canada CF-105 Arrow (Source: Ken Mist, CCSA)

In 2017, the Dedave UAV has been licensed by the Canadian maritime technology company Kraken Robotics, who have renamed it to Thunderfish Alpha. Since the end of July, the underwater robot has been helping the company to hunt down the Avro Canada CF-105 Arrow interceptor aircraft in the waters of Lake Ontario. While the aircraft’s development and testing phase, conducted from the shore of Lake Ontario, some jet prototypes and their parts were scattered over a large portion of the lake. In September, the UAV located the first and shortly after a second model of the Arrow jet, for which people have been looking for 50 years. Based on acoustic echoes, the diving robot generated sonar images in real-time, which were analyzed by the experts directly after the dive. Image data could be transferred wirelessly, and gave precise indications of potential item locations.

Also in 2016, the 25-students team Sonia of École de Technologie Supérieure in Montreal started to build an autonomous underwater vehicle using modular CAN architecture inside the vehicle. The hardware within the submarine included a navigation system, cameras, six motors, a bright light, a torpedo launcher (a demonstrator version), and two small robotic arms. For connection of the CAN network to a PC, Sonia has ▷

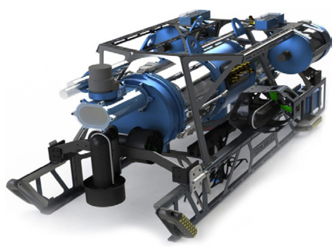


Figure 7: The Sonia AUV dives with Kvaser interfaces (Source: Kvaser)

used the Kvaser USB-CAN II interface for many years and then a Kvaser Leaf Pro HS v2. As Linux users, the team chose Kvaser CAN hardware because of company's support for both Windows and Linux. The students used open-source software and have also created an open-source package for robotic systems that interface with Kvaser devices. The interface is built on ROS (robotic operating system), a popular middleware for robotic projects.

For actuation under water

As an example for CAN-connectable devices deployed in submarines, Olsen Actuation (UK) provides the OLX linear and ORX rotary actuators withstanding pressures up to 300 bar. Optionally, the devices come with integrated servo drive electronics and multi-axis operation. Further options include secondary redundant sealing systems, salinity sensors, temperature sensors, and pressure-level sensors. Manual docking, side- or rear-drive, visual position indication, diverse mounting arrangements, as well as marine subsea-rated cables are offered. Customization of the actuators e.g. regarding housing materials, is possible. OLX and ORX actuators are built around the company's Exlar GSX actuators, which has been proven time and again on Virginia Class nuclear submarines. The devices are suited for applications in submarines such as winch brake control, winch cable guide control, umbilical cutters, hatch and door actuation, sonar array cutters, and sonar mast deployment. They also find application in pipeline inspection tools, thrusters, and manipulators.

Figure 8: The CANopen i127 servo drive is dedicated for thruster control on under-water vehicles (Source: Ingenia)

The Spain manufacturer Ingenia Motion Control provides the CANopen i127 brushless AC motor servo drive including pressuretolerant electronics. Dedicated for ope-ration at up to 1600-m deepness (up to 160 bar), it can be used for control of propulsion systems on manned submarines, AUVs, ROVs (remotely operated vehicles), or other underwater vehicles. The device implements the CANopen device profile for drives and motion control (CiA 402 and IEC 61800-7-2/-3). Historically, electronic systems for deep-water applications have been installed inside of low-pressure vessels. Working with pressure-tolerant electronics reduces the weight and volume of containers as well as the number of connections through pressure barriers. The power and electronic systems are not placed in the submarine cabin. Less complex and reliable cooling systems are required. Use of such electronics also reduces system complexity and increases reliability. Thereby, several design issues should be considered. Full isolation between power and logic connections should be given. Dynamic braking should be done through on-board high-power shunt braking resistor. For operation, full disconnection from batteries should be achieved. Furthermore, on-board self-monitoring systems for voltage, current and temperature supervision are required. Protection systems should not provide non-resettable devices i.e. all protections should be electronic.

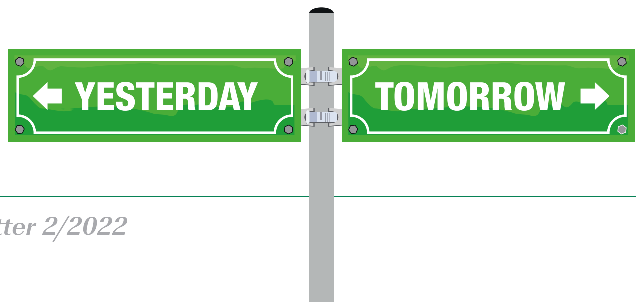
Summary and outlook

CAN is broadly used over and under the sea because of its high reliability, price-performance ratio, and available off-the-shelf hard- and software infrastructure. Advanced standardization of CAN-based communication interfaces enables simplified development, integration, and replacement of devices.

Redundant use of devices and networks is a must for the maritime applications. CiA and its members is currently working on a generic dual-mode redundancy solution for CAN-based interfaces independent of the used CAN data link layer protocol. It should suit Classical CAN, CAN FD, and CAN XL.

NMEA 2000 uses Classical CAN communication with 29-bit CAN-Identifiers. The association is not (yet) willing to use CAN FD and CAN XL. The features of Classical CAN (bit-rates of up to 1 Mbit/s and payload size of up to 8 byte) seem to be sufficient for such maritime applications.

For electronics used under the water, special design issues have to be considered. These relate to the housing robustness, pressure-compensation, isolation of power ▷



Proprietary CAN solution for maritime systems

The E-POD propulsion solution is one of company's example products, which can be connected to the Vetus network (Source: Vetus)

Vetus (Germany) has designed a proprietary V-CAN (Vetus Controller Area Network) system, which is intended for company's products only. The company has also manufactured gateways, which communicate between the V-CAN system and devices implementing J1939 or NMEA 2000 higher-layer protocols. The firm assisted the NMEA organization in the implementation of thruster and electric propulsion to operate on that network.

The proprietary protocol enables the company to stay in control and maintain the safety factors implemented within its products. External control or monitoring by other systems requires manufacturer's approval. This can be done either via a gateway to the other system, or through approved use of the V-CAN command structure.

J1939 analysis for ship telematics

Vives recorded data from the GEOxyz maritime vessel (Source: CSS Electronics)

Vives is the largest university of applied sciences in West Flanders (Belgium) with campuses in five student cities. The university participated in a European-funded project ISHY (implementation of ship hybridization) that wants to achieve 50 % of CO_2 reduction on medium ships. The project researches the possibility to use fuel cells, battery supply, and hydrogen in ships in place of heavy fuels.

To calculate the size of the alternative power supplies exactly, the project members needed to know how much power the combustion engines deliver at any time. The examined GEOxyz vessel has two engines (port and starboard) interconnected via two J1939 networks. Therefore, the actual engine speed and the actual engine torque values coming from the two in-vessel networks were monitored and logged. With those two parameters it was possible to make a power profile of the combustion engines. The CANedge2 data logger by CSS Electronics was used for logging of these parameters. Further, the researchers wanted to know why the engines require this amount of power. For this, a third network was set up and the data was logged by a second CANedge2 device. On this network, a GPS (global positioning system) receiver, IMU (inertial measurement unit), wind speed sensor, wind direction sensor, wave sensor (and more) were implemented. The two CANedge2 units uploaded the log files from their SD cards via the 4G mobile network to the third-party S3 server from AWS. Finally, the data could be displayed on a monitor in the office using the Grafana dashboard software tool.

supply, cables and connector protection, and many more. In the meantime, there is a number of companies offering a long-term experience and support for CAN-based (sub-) marine product developments. ◀

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