CANopen for small drives

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Abstract
Although designed as a fieldbus with line lengths of several meters, CAN networks today are widely accepted as an embedded communication system within compact machinery and devices. For applications, where space is limited Maxon Motor offers compact positioning controllers with CANopen interface. Apart from introducing compact CANopen-compatible positioning controllers, this article highlights various options on how the movements of several drives can be synchronized with CANopen. A miniaturized high-end robotic controller is referenced as an application example.

With the continuing miniaturization of electronics and increase in the power density of electrical drives, many machines and devices can, today, be built much more compactly than they were a few years ago. And because fieldbuses such as CANopen are used, there is still very little cabling despite an increasing number of sensors and actuators. Even when there are significant price pressures on machinery, using a fieldbus can still be worthwhile. The CAN technology is known as a low-cost bus, not least thanks to the availability of a large number of micro-controllers and processors with integrated CAN controllers.

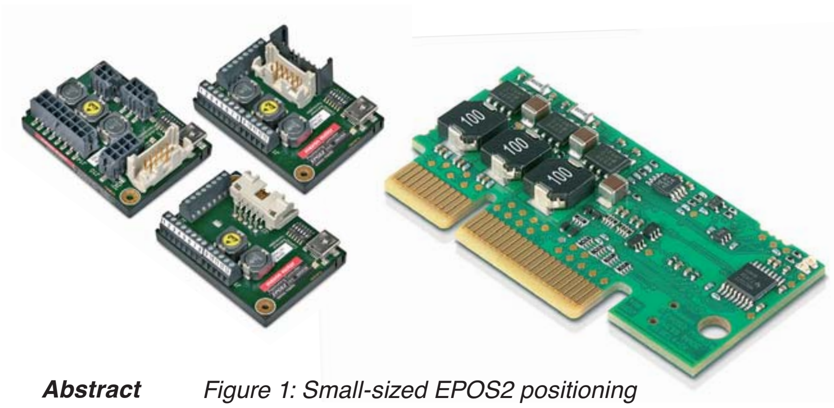

Figure 1: Small-sized EPOS2 positioning controller with CANopen interface

The use of the standardized CANopen protocol according to CiA 301 and device-specific profiles such as CiA 402 significantly reduces the development cost of the control software. Developers also have greater flexibility, as individual devcies can be exchanged without major changes. If, for example, a stepper-motor with relevant controller is replaced by a DC-motor with another manufacturer's controller, the machinery's control software hardly changes, as both drive systems appear almost the same on the CAN network when using CANopen profiles.

Just as the size of electrical drive systems and the costs are falling, so the requirements placed on performance and functional range are increasing all the time. And even for smaller devices, it is becoming increasingly important to synchronize individual drives with each other to realize more complex motion processes.

Control units for high-performance micro-drives

With EPOS2, Maxon Motor offers a family of universal positioning controllers for DC- and EC-motors with 1-W to 700-W nominal output. The EPOS2 24/2 controllers with up to 48-W nominal output were specifically developed for use in compact machinery, and the EPOS2 Module 36/2 with 72-W nominal output for OEMs (Figure 1).

The functional range of these controllers is largely identical to that of the larger EPOS2 drive controllers. EC-motors can be operated at up to 100000 rpm (rotation per minute), and due to a maximum of 2500000 encoder pulses, high-resolution encoders may be used while the encoder input frequency may be up to 5 MHz. Apart from CANopen according to CiA 402, communication interfaces offered by these EPOS2 controllers are also USB and RS232 as well as gateway functions of USB or RS232 to CAN.

These small controllers also support a wide range of operating modes, e.g. position, velocity or current mode. There are also functions such as "Step/Direction Mode" for the incrementally controlled movement of the motor shaft or "Master Encoder Mode" for applying the drive as electronic gearing. With the graphical user interface "EPOS Studio", these controllers can be efficiently parameterized and adjusted.

Synchronization of several drives via CANopen

For many multi-axis applications, it is sufficient for drives to move independently from each other. The drive controllers are typically operated in the "Profile Position Mode" or the "Profile Velocity Mode". In order to synchronize the movement of several drives, as required for multi-axis positioning systems, CANopen specifies several options. One preferred variant is the use of the "Interpolated Position Mode" (PVT, Position and Velocity versus Time). The host controller calculates the movement of all drives, periodically generates position and velocity support points, and writes these into the positioning ▷

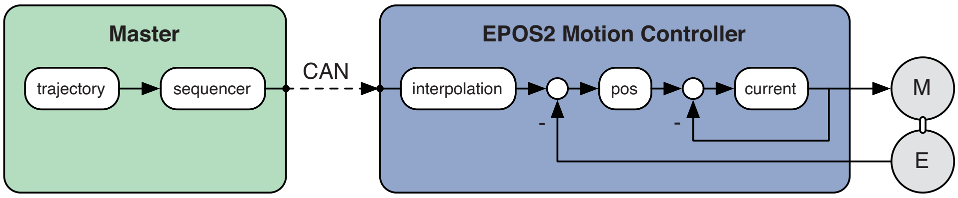

Figure 2: Periodically setting support points for the "Interpolated Position Mode"

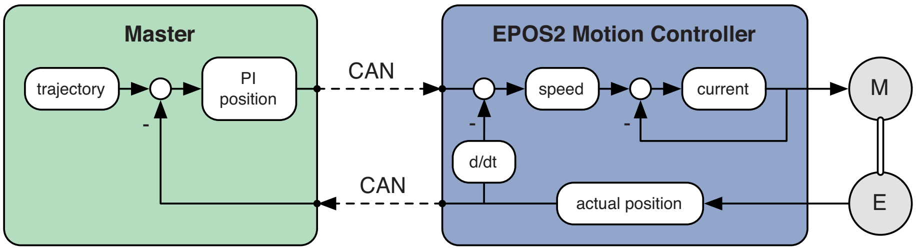

Figure 3: Control-loop closed via CAN with velocity set value by the host controller

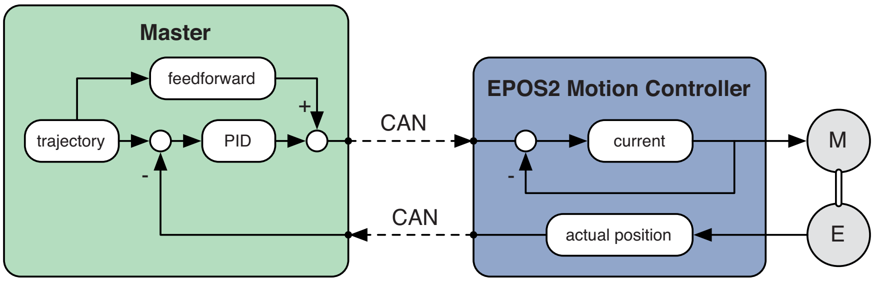

Figure 4: Control-loop closed via CAN with current/torque set value by the host controller

controller's message buffer. The motion controller in turn calculates set values for position control by linear or cubic interpolation. Positioning controllers' local timers can be synchronized on the CANopen network with the SYNC messages (Figure 2).

The periods between the support-points of the "Interpolated Position Mode" are typically between 10 ms and 100 ms, with the busload and real-time requirements on the host controller being low. However, one drawback of this operating mode is that motion cannot be changed very quickly.

If, for instance, motion is additionally synchronized with external sensors (vision, encoder from conveyor or belt), this type of motion planning and control is too slow. Potential applications, where "Interpolated Position Mode" is useful are the automatic tracking of telescope and solar mirrors, or control of machine tools, where the movements of the axes are pre-determined.

Higher dynamics in motion planning can be achieved if motion planning and a part of drive control are carried out entirely in the CANopen master, e.g. with a position controller in the master and subordinate speed controllers in the drive controllers (Figure 3). The controllers are then operated in the "Profile Velocity Mode", but care must be taken to ensure that set values are applied immediately; otherwise the position control-loop cannot be closed. The EPOS2 positioning controllers also offer a true "Velocity Mode", which feeds velocity set values directly to the motion controller, leading to high control dynamics. The busload plus the requirements placed on the host controller's real-time capability are much higher with this control architecture, with cycle times of typically between 2 ms and 5 ms.

Another possibility involves realizing the position and velocity controllers in the master and setting the desired torque or current values in the drive controls via CANopen. To do this, CANopen specifies the "Profile Torque Mode". As an alternative, the EPOS2 controllers offer a "Current Mode" which directly feeds current set values to the current-controller via the CAN network (Figure 4). This leads to a high dynamic range, which is essential for coreless motors.

By directly commanding the current set value, more complex control algorithms can be implemented in the host controller, as required, for example, in robot systems with non-linear dynamics. Nevertheless, apart from sufficient processing power on the host controller, this architecture also needs hard real-time capability, as cycle-times should be around ≤1 ms. Such short cycle-times use up a great deal of the CAN bandwidth. Example: Sending a CAN message with a current set value and receiving a message with the actual position lasts almost 200 µs per drive at a transmission rate of 1 Mbit/s (see Table 1). A required cycle-time of 0,5 ms for only two drives on the CAN network already utilizes around 80% of the bandwidth.

Example: The PocketDelta robot

Asyril located in Villaz-St.-Pierre (Switzerland) has developed a micro-robot with delta kinematics for micro- ▷

Figure 5: asyril's PocketDelta robot

CANopen message	Data length	Duration at 1 Mbit/s
RPDO with current set value	2 byte	82 μs
RPDO with current set value, Controlword, Mode of Operation, digital outputs	7 byte	122 μs
TPDO with actual position	4 byte	98 μs
TPDO with actual position, Statusword, digital inputs	8 byte	130 μs
Heartbeat	1 byte	74 μs

Table 1: transmission times for different CAN messages

Conclusion

CANopen is suitable for use in compact machinery and apparatus, not least because it is inexpensive. With the EPOS2 24/2 and EPOS2 Module 36/2 positioning controllers, Maxon Motor provides CANopen-compatible drive solutions for confined spaces. Several drives can also be easily synchronized via the CAN network through support from various types of operating modes, including "Interpolated Position Mode". As the PocketDelta robot's controller shows, it is possible to realize highly challenging motion control applications using CANopen.

technology applications. With this kinematic structure a small platform with a gripper is moved in 3D space with parallelograms. Three motors drive the parallelograms (Figure 5). The robot's moving mass is therefore very low, making top acceleration and velocity possible.

The drives used are Maxon EC-i motors with 40-mm diameter and 50-W nominal output. With an internal, multi-pole rotor, these motors typically feature low-time constants, making them highly dynamic and giving them high-torque density. The EPOS2 Module 36/2 positioning controller drives these motors. This device is placed into the card slots of a motherboard developed specifically for small robots with up to four drives (Figure 6).

An ARM11 processor with on-chip CAN modules is used as host controller. This processor also sits on the motherboard and communicates with the EPOS2 via the CAN network. Other EPOS2 controllers, e.g. for feed systems or transfer axes, or even other CANopen devices, could be connected to the host controller providing NMT master functionality.

Highly dynamic robots such as the PocketDelta that can reach accelerations of 5 g and velocities of 2 m/s place high requirements on the drive controls. The dynamic equations of such systems are normally nonlinear and also coupled between individual drives. To reduce tracking errors to as few µm as possible at high acceleration and velocities, in addition to a specially designed feedback controller, a feed forward controller that calculates the entire robot's dynamic equations is applied.

The EPOS2 Module 36/2 controllers are operated in "Current Mode". In addition to motion planning, which must be synchronous for all drives, the host controller also calculates the control algorithms and the dynamic equations. The host controller then transmits the resulting current set values to EPOS2 via the CANopen network. The actual motor positions are captured with high-resolution encoders and sent to the host controller by PDOs from the EPOS2. This way, position and velocity control is closed through the CAN network (Figure 4). With an optimized definition of PDOs featuring as short a data length as possible and the various drive controllers divided onto two CAN networks, cycle-times of well under 1 ms can be achieved for control purposes. ◀

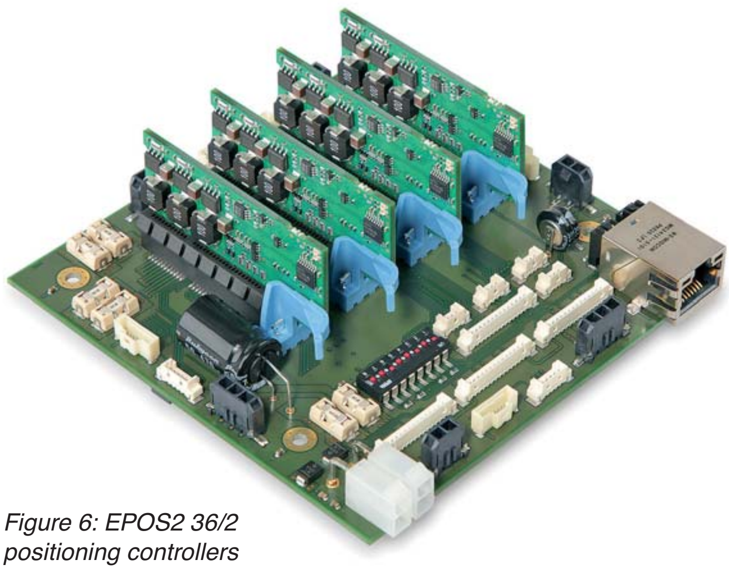

Figure 6: EPOS2 36/2 positioning controllers with motherboard

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