CAN-based control system for compact loaders

Norcar and TK Engineering (both Finland) jointly developed the J1939-based control system of the Norcar's recent compact loader.

When Norcar began developing the new a7750 compact loader, it needed to lift more and go faster than any of the previous models. This required a new, more powerful diesel engine – one that also complied with the latest EU emissions regulations.

The engine was the initial reason TK Engineering (TKE) became involved in the project. It was a modern Kubota diesel engine, equipped with an SAE J1939 CAN interface. Since earlier Norcar machines relied largely on mechanical engine controls, they needed someone that could help them set up the connection to the engine. With many years of hands-on experience with J1939 systems – and located close to Norcar – TKE was the natural choice to get it up and running quickly.

The initial goal was simple: get the engine communicating and running. That was achieved during the very first visit. From there, the project gradually grew to include development of the entire machine control system and its CAN networks.

The end result was a fully digital control system – and a machine that went on to become the winner in a test of 15 of Europe's leading compact loaders.

But let's return to the new engine. For the new model a7750, the Kubota engine was selected not only for performance, but also for compliance with EU Stage V emissions regulations. These regulations introduce new control requirements, particularly around exhaust after-treatment. The engine is equipped with a diesel particulate filter (DPF) that must be monitored and periodically re-generated to prevent build-up of soot. Re-generation can only be performed when operating conditions are safe and this, in turn, requires the engine control unit (ECU) to communicate with the operator of the vehicle, who decides when re-generation is allowed.

While previous Norcar models used mechanical and electrical controls, there was now a need to control the en-gine using CAN and J1939, and to manage the DPF filter re-generation. This would require a PLC-based control system, a digital display, control software, and a robust J1939 network.

Joint development of the control system

Development of the a7750 control system was a close collaboration between TKE and Norcar. TKE was responsible for:

- Control system software for the VCU (vehicle control unit);
- Software for the operator display;
- Design and architecture of the CAN networks.

Norcar, in turn, developed the rest of the machine, including wiring, sensors, hydraulic components, operator controls, and mechanical systems.

The smooth operation of a machine depends not only on the software. The team also had to understand hydraulic propulsion, valve behavior, engine characteristics, and electrical wiring. PWM (pulse width modulation) outputs were tuned for optimal valve control, filters were implemented to suppress contact bounce from physical buttons, and extensive work went into managing the PLC's functional safety framework, including hundreds of possible error conditions. TKE also completed the original task of the project, to design the CAN networks of the machine, and provide tools for CAN diagnostics.

CAN-based control system benefits

After the decision to have an all digital control system based on the CAN, there were many things that could now be implemented, that could not easily be done on the old mechanical-electrical control systems. The benefits include:

- Improved machine control: Electronic throttle and speed control enable filters and ramp functions to be implemented in software, improving precision and operator comfort in demanding environments.
- Reduced wiring complexity: CAN networks combine multiple signals on the same physical wires, significantly ▷

reducing wiring complexity, installation time, and potential failure points.

- Enhanced flexibility: With software-driven control logic, functionality can be modified simply by updating the control software, often eliminating the need for hardware changes.
- Advanced logic implementation: Replacing relays and switches with programmable controllers allows for the development of more sophisticated logic, leading to more flexible and efficient machine operations.
- Fault and status management: CAN networks support comprehensive data exchange between smart devices. This allows distribution of detailed status and fault information in the system, enabling the display of error messages as well as many engine and system variables on the operator screen.
- Simplified diagnostics: With most signals available on CAN, diagnostics become as simple as connecting a laptop. On the Norcar a7750 a dedicated J1939 diagnostics connector gives read-only access to the system data, allowing live monitoring using tools such as TKE's CANtrace bus monitor.
- Enhanced safety: Digital control makes it easier to implement safety features, such as automatic parking brake engagement if the operator leaves the seat, start-inhibit when the gear is not in neutral, or limp-mode operation when unsafe conditions are detected.

Designing for functional safety


Figure 1: Norcar a7750 compact loader (Source: Norcar, TK Engineering)

With throttle, speed control, and braking now handled electronically, functional safety became a central requirement. This required the use of a safety PLC, and a development process that would take into account the requirements for functional safety.

TKE development team did this by adapting the company's existing software development process. Each machine function was documented, designed, coded, tested, and verified based on a formal functional spec-ification.

There's a lot of talk about hardware-in-the-loop testing, simulations, and digital twins. A machine can be designed and tested digitally before it even exists in reality. But considering the cost of creating and main-taining a digital twin or even a hardware-in-the-loop test, the team opted for a more traditional test setup.

Testing was carried out in three stages:

1. Automated software tests: The control logic was clearly separated from the hardware interface, allowing it to be tested on the development workstation using automated tests.

Figure 2: A dedicated J1939 diagnostics connector gives read-only access to the control system data, allowing live monitoring using TKE's CANtrace bus monitor tool (Source: Norcar, TK Engineering)

2. Desktop hardware setup: The controller, display, pedals, buttons, and indicators were assembled into a compact test rig. CAN communication was monitored, and the CAN signals of the engine ECU were transmitted using the CANtrace tool. Developers could manually operate the system, almost as if driving the machine.
3. Full system test on the machine: Finally, the control system was tested as part of the machine. Every function of the machine was tested manually, by following a step-by-step list of actions to perform and results to expect. This included operating the machine on a test range, but also fault injection, such as disconnecting wiring or triggering faults through the CAN network.

The full system test was a formal part of the functional safety process and verified that every machine function and safety function worked as intended. The other test stages mostly duplicated the system test, but as they could be performed in the office, they greatly reduced the time the developers needed access to the machine.

While automating the tests on the machine would have been exciting, it was much more efficient to perform the tests manually. All mandatory tests could be performed manually, on the prototype machine, in a single working day. Automation would have required months of deve-lopment and scrapping a new machine to make the test platform.

Just as importantly, the time spent driving the machine provided invaluable insights. Operator feedback, real-world usability, and hands-on experience helped refine safety functions and improve overall operator experience – benefits that would have been difficult to achieve through simulation alone.

CAN network architecture

The project began with a single J1939-based CAN network connecting the ECU, the VCU, and the operator display. When a diagnostics connector was added, a second CAN network was introduced to prevent unrestricted access to critical control signals. Through this secondary network the software of the VCU and display could be updated. Later gateway functionality in the VCU also provided limited, controlled access to the main CAN network when required.

Since the engine already used J1939, and no alternative protocol offered clear advantages, all network messages were designed according to the SAE J1939 standard, with proprietary messages defined for communication between the VCU and the display.

In summary

I enjoy making control systems for machinery. The way the software connects to the real world, spinning wheels on the ground, or turning a water jet nozzle on a fast-moving vessel at sea, or lifting cargo in a port. You have to take into account complex layers of functional safety as well as operator interaction, making the machine a pleasure to operate but at the same time make sure the controls will behave in a predictable way even when there are component failures.

There's also the thrill of learning all the machine systems, to understand how the software interacts with mechanical and hydraulic systems, taking into account delays and limitations of the machine in the software design.

And of course, nothing beats getting to operate actual machinery, or taking a ride with the operator when you are not qualified to operate it yourself. ◀

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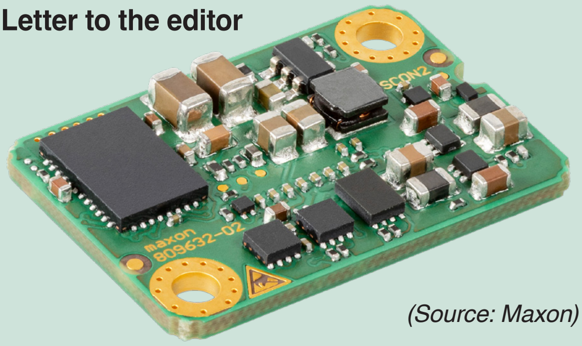
Letter to the editor



(Source: Maxon)

Daniel Hug (Maxon, Switzerland) clarified in an email that only the miniaturized Escon2 Nano 24/2 motion controller (23 mm by 16 mm) does not comprise a CAN transceiver (see CAN Newsletter issue December 2025). It needs to be externally added. All other Escon2 devices provide an integrated CAN transceiver.

Additionally, he wrote that the entire Escon2 product range supports current/torque and velocity control as well as the associated CiA 402 modes such as CST, CSV, and PVM. Therefore, they can directly replace other CiA 402 compliant devices as long as position control is not required.

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