A Miniaturized Motor Control Unit for Space Exploration Missions

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The ESA project Miniaturized Motion Controller Customization for Exploration (MCC-X) aims to develop and validate a general and standardized motor controller to form a complete integrated node in a distributed motion control system. The product to be developed in the project is a miniaturized motion control device designed to withstand the environmental requirements of several different space applications, including the Martian environment and geostationary orbits.

The Miniaturized Motion Controller Customization for Exploration (MCC-X) is designed to be a closed-loop motor control unit with a simple interface. The latter consists of only connectors for power and standardized communication buses, towards the user platform in order to enable distributed motor control. The unit is very compact (<120 cm³) and must withstand the extreme environment of space exploration missions. The targeted non-operational temperature range is -130°C to +100°C. In order to cope with such harsh requirements, it is realized using hybrid mounting technology, where several modules are assembled on a carrier which is placed in a single enclosure (Figure 1).

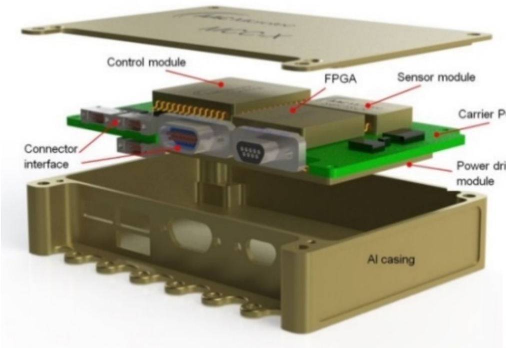

Figure 1: Conceptual view of the MCC-X assembly.

Each MCC-X unit is a stand-alone component that includes modules for power drive, control and sensing. It allows the autonomous operation of a brushless motor (or up to two brushed motors) in torque, position or velocity mode. A radiation tolerant FLASH-based field-programmable gate array (FPGA) performs closed-loop motor control as well as the communication over CAN bus (or optionally SpaceWire) with a host unit. The unit also has an internal heater. The MCC-X design is modular in terms of the available subsystems: power electronics for driving the motors, on-board logic for implementing the control algorithms, telemetry functionality and sensor data acquisition. The reconfigurable FPGA allows customization of the design according to the needs of various applications.

The ESA project MCC-X is a follow-up to an earlier MCC activity with the goal of advanced miniaturization and higher computation power. Both CSEM and Maxon Motor are again part of the consortium. CSEM is in charge of the development of the FPGA firmware and host-based graphical user interface (GUI). Maxon Motor contributes to the definition of requirements, review of the electrical design and is responsible for functional and environmental testing.

All communication protocol and motor control logic is implemented directly in FPGA firmware. No soft processor is used. This reduces the hardware components and fault-sources significantly, as no external memories are needed. Advanced techniques like triple modular redundancy (TMR) can be used for further radiation-hardening of the FPGA design.

For closed-loop motor control, the FPGA implements cascaded proportional-integral-derivative (PID) controllers, filters and interpolators (Figure 2). To save resources, all these operations are implemented in time-multiplex with a single multiply-and-accumulate (MAC) instance.

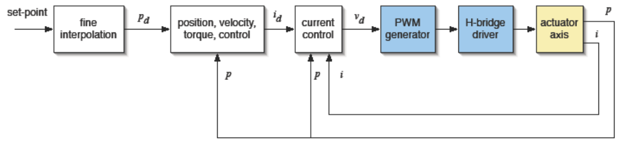

Figure 2: Closed-loop motor control block diagram.

An application-specific digital-signal-processing (DSP) engine in the FPGA implements a 32-bit fractional data path, by using a single 16x16 bit signed/unsigned HW multiplier, a 32-bit barrel shifter and a 64-bit accumulator. At every clock cycle, the intermediate result of the multiplier is fed to the accumulator, correctly shifted and sign/zero extended. The 32-bit read-out of the accumulator is saturated and can get clipped to lower and upper boundaries.

In the FPGA design, a programmable sequencer controls the DSP engine. The assembler for the sequencer and DSP engine, but also the many GUIs for different motor configurations and motor control applications were developed in Python (Figure 3).

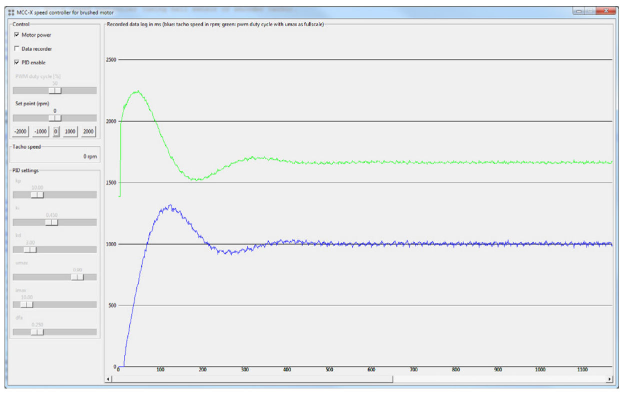

Figure 3: Example Python GUI for motor speed PID control.

The motor H-bridges are controlled from the FPGA using pulse-width modulated (PWM) outputs. For closed-loop control, various digital and analog inputs (ADCs, Hall-effect sensors, digital encoders etc.) get processed in the FPGA. To calculate motor speed from measured pulse lengths, the DSP engine got extended to support radix-2 divisions.

Overall, this results in a very compact closed-loop motor control implementation, outperforming the requirements with a substantial margin.

The project is currently in the design stage. A second generation of prototypes has been manufactured and is used for validation of both hardware and firmware performances.