Development of a Universal and Scalable Mechanism Control Electronics Configured to Application Solely by Parameter and Software Configuration

Udo Rapp* and Juan Camilo Garcia Hernandez*

Abstract

Modern motor-driven high-precision mechanisms require dedicated control electronics in order to achieve their individual function, e.g., position, velocity or acceleration control. The development of Mechanism Control Electronics (MCE) is therefore often driven by necessary engineering development or optimization tasks for this individual function rather than by economic and life-cycle requirements.

The new concept of a universal Mechanism Control Electronics, co-funded by the German Space Agency (DLR), breaks up with the engineering optimization approach as generally applied to each specific project and demonstrates that one electronics unit is able to serve numerous mechanism applications at minimized adaptation need.

With the presented development of a new control electronics, a versatile light-weight, low-power, low-volume and low-cost solution applicable to a large variety of different mechanism control requirements could be realized.

Introduction

In the past decades, several generations of Mechanism Control Electronics have been developed at Airbus Defence and Space, including Solar Array Drive Electronics, Antenna Pointing Electronics for LEO/GEO as well as Mechanism Control Electronics for various science scanning and pointing applications.

Each of these drive electronics has been a highly integrated unit with strong regard to volume/mass and power budget and was adapted to the specific mechanisms and system requirements in order to optimize the equipment function to the dedicated customer needs.

The new concept breaks with the optimization for each single application and transfers all operation modes, control loops and telecommand/telemetry functions into software instead. In addition, the interfaces to spacecraft and to the mechanism are implemented fully flexible to be universal for different mechanism/actuator types and for different spacecraft bus interfaces.

This paper describes the collection of versatility requirements and the development performed on the different Mechanism Drive Electronic modules with the resulting Electronics Demonstrator Model. The "Application Summary and Conclusion" section contains the present status of the Universal Mechanism Control Electronics and describes its flexibility with respect to the mechanism motor characteristics, command/telemetry interface and specific function.

* Airbus Defence and Space GmbH, Friedrichshafen, Germany
udo.rapp@airbus.com, juancamilo.garciahernandez@airbus.com

Requirements Analysis

The development work was started with a requirements analysis to determine the key requirements enabling a Control Electronics to become a ***universal*** Mechanism Control Electronics. These requirements include the following major technical key aspects:

Primary power bus variability: Capability to operate at all standard primary power bus voltages, i.e., 28V unregulated up to 50V regulated bus.

Power Drive capability: DC/DC Converter and motor amplifier shall be scaled to comply with the majority of space mechanisms. An open architecture for equipment with higher power demand shall be granted.

Command/Telemetry variability: The unit shall operate at all typical interface topologies, i.e., Mil-Std-1553B, RS-422, SpaceWire, ML16/DS16, etc.
Eventual hardware modifications for interface-adaptation shall be kept to an absolute minimum.

Operational Mode Control: Handling of mechanism operational modes (e.g., standby, movement, autonomous functions) shall be completely handled in software.

Current- and Motion-Control Loops:
Transfer of all motor current-, torque-, position-, velocity-control loops into real-time-operating software.
Bandwidth target above 100 kHz (bandwidth to be distributed to all control loops)

Mechanism Actuator Interface: Interface to brushless-DC Motors, brushed-DC motors, Linear Actuators or Stepper Motors at only minor and pre-defined hardware adaptation

Motor Filtering/Damping: Motor mechanical characteristics differ significantly with respect to motor type (stepper/BLDC/DC) as well as the motor electrical characteristics. It is mandatory that the universal MCE either allows proper EMC filtering / damping for a high range of motors or, as an alternative, facilitate adaptation to specific motor characteristics.

Position-Sensor Interface: Interface provision to analog and digital, incremental and absolute optical encoders. Interface to reference switches, external and motor internal Hall Sensors.

Open Architecture: Clearly defined interfaces to open the universal Mechanism Control Electronics to other or new mechanism and interface types.

Requirement Summary: One universal Mechanism Control Electronics shall be capable to serve at least 90% of mechanism targets (major application bandwidth) without or with minimized non-recurring effort in hardware adaptation.
The open architecture shall allow the adaptation to the other 10% of upcoming mechanism applications.

Overall Architecture

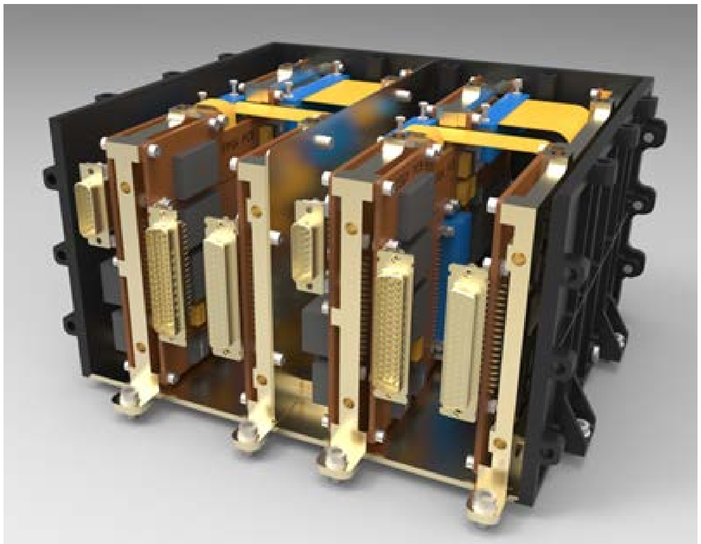

Figure 1: Universal MCE in cold redundant configuration

Housing definition

The MCE housing design is based on module frames for each module with separate box outer walls. Flexibility to missions with severe radiation requirements can be achieved by adding additional shielding thickness to these box walls (no change of electronics parts due to changed radiation requirements). The unit structural analysis shows first resonance frequencies above 490 Hz in all axes with sufficient margin to the expected loads and confirms the selected “module frame approach”. Both main and redundant units are integrated within one enclosure, separated by an internal aluminium wall.

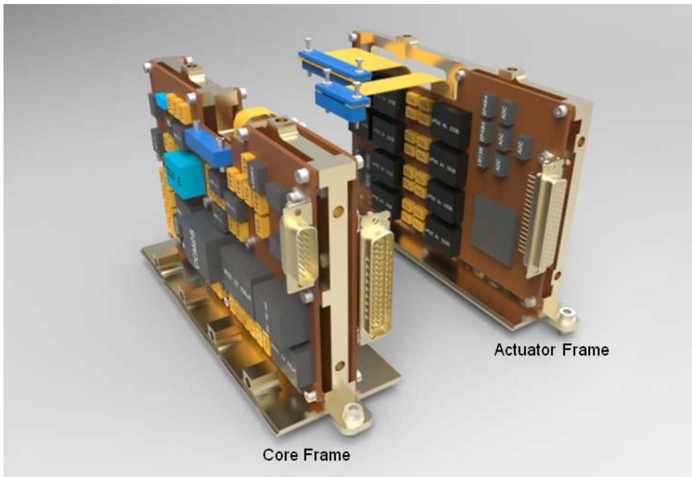

Figure 2: Core and Actuator Frame universal MCE

MCE module distribution

Different concepts have been regarded in order to achieve the distribution of functions to the different MCE printed circuit boards. Following the major requirement for useability in a majority of applications, the modules have been separated into

- Core Frame with the mechanism controller system and the interface to primary power
- Interface Board as a plug-in module to the Core Frame
- Actuator Frame with motor amplifiers and position sensor acquisition circuits

The electrical interfaces between these modules have been standardized to allow the usage of different Interface Boards or Actuator Frames without design adaptation needed on the Core Frame.

Core Frame (DC/DC Converter, Controller System and Software)

DC/DC Converter

Typical electronics units on a spacecraft provide dedicated building blocks to realize different spacecraft primary power bus voltages. Associated engineering and design effort are frequently required to adapt the unit, e.g., from 28V unregulated towards a 38V regulated power bus.

In order to avoid this adaptation from program to program, the Core Frame primary bus interface has to be able to cope with an enveloping input voltage range from 22V up to 52V without the need of any commissioning or adjustment need. A new converter architectural concept has been established, which combines the MCE EMC input filter together with sequential converters for actuator power and internal supply. The galvanic isolation is maintained by this converter concept.

Mechanism Controller System

Field Programmable Gate Arrays (FPGA) with hard-coded firmware (VHDL) are frequently used in Mechanism Control Electronics to combine the specific mechanism control and sensor acquisition interfaces with intelligent mechanism mode control and interface handling. In most cases, the motor current controller or sensor analog acquisition circuits are kept analog and are adjusted for different motor and sensor characteristics.

For a universal Mechanism Control System, it is mandatory to consequently transfer unit operational functions and parameters into software, together with actuator control loops and motor current controller. The selected architecture achieving a standardized controller concept is depicted in Figure 3. This complete architecture has been introduced into one FPGA embedded system and completes the Core Frame together with the DC/DC Converter defined above.

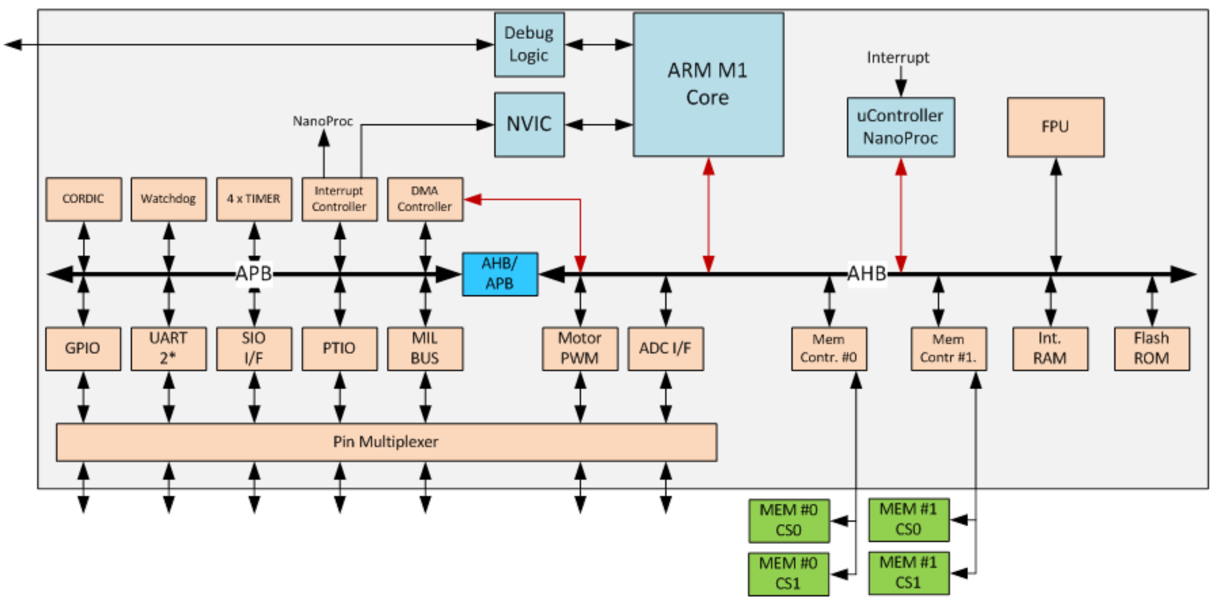

Figure 3: Mechanism Controller System of Universal MCE

Besides the logic blocks for command/telemetry interfaces and the actuators and sensor interfaces, the major constituent is a dedicated processor system consisting of two processors plus a Floating Point Unit (FPU). An ARM-M1 processor is responsible for the mechanism functions and operation, whereas the NanoProcessor together with the FPU performs all control loop tasks in virtual real-time.

The overall processing performance is 23 MIPs, 10 MFLOPs (32-bit-float) plus 1.11 MFLOPs (trigonometric) which allows a control-loop bandwith of >100 kHz that can be distributed to current, position and velocity control.

Software

The universal MCE software has been developed following a software layer model. This allows introduction of new mechanism operational modes as well as additional real-time control loop tasks without need of full software re-development. Basic operational modes are available but additional user-defined modes can be added without restrictions.

Figure 4 shows the functional distribution of software modules and control loops to the two processor systems and the interface of new modes/control-loop functions and parameters to the MCE software. The basic software blocks within the ARM M1 Processor and within the nanoProc remain unchanged for all MCE appications.

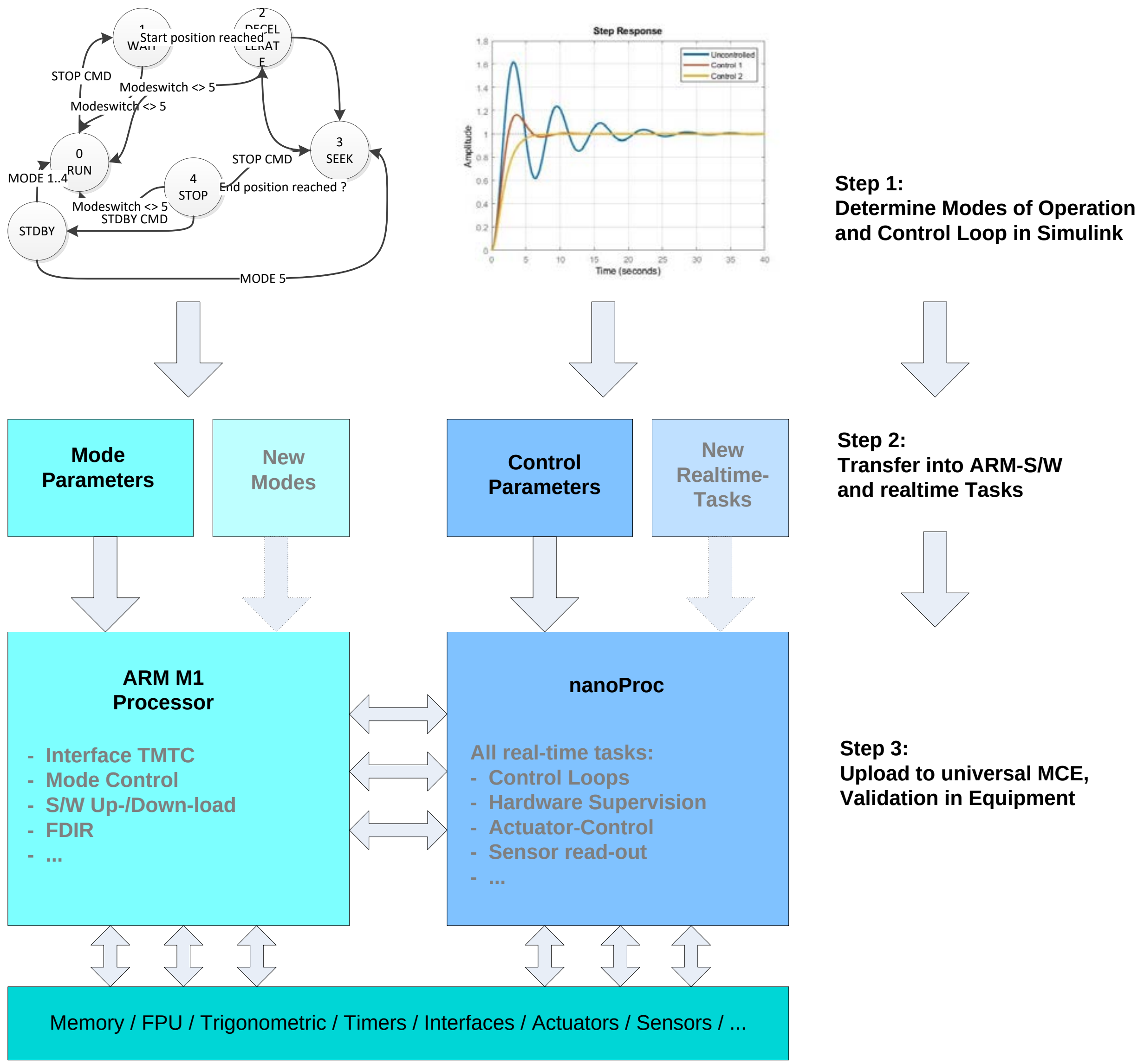

Figure 4: Distribution of Software to the two processors

Interface Module

The interface modules consist of simple electrical level shifters to comply with the interface electrical protocol, all logic protocol tasks are performed in the Controller System. A set of different interface modules, e.g., for RS-422 interfaces, Mil-Bus 1553B topologies exist. The interface module has been mechanically sized to allow the application of an additional programmable component (FPGA) to support other interface or bus topologies that have a high performance demand.

Flexibility with Dedicated Actuator Frames

The biggest challenge in developing a universal Mechanism Control Electronics results from the high variety of available motor types, motor characteristics as well as the sensor type for position, velocity or acceleration sensing.

In motor amplifier design, EMC filtering and motor current damping is a function of motor amplifier topology (linear versus PWM technology), PWM frequency, maximum motor current amplitude, and required damping over frequency. Besides this, the motor characteristics (inductance, coil resistance, Back EMF voltage) and proper dimensioning/shielding have significant influence to the EMC behavior of the system and therefore also to the behavior of the required filter.

Although one filter design can fit to a range of motor characteristics, adaptation to significantly different characteristics will always be necessary. This is especially the case for low-inductive motor type in high-velocity systems compared to higher inductive motors in low-velocity / high-torque systems.

The same is valid for the sensors measuring position and velocity of the mechanical system. These sensors follow the operational and accuracy demands of mechanical systems and typically differ from equipment to equipment.

- During the development work it became obvious that one single electrical circuit dedicated and optimized to one specific motor characteristics can never serve completely different motor topology and characteristics.
- Sensor acquisition electrical circuits within the universal MCE need the flexitility to adapt to sensor characteristics, sensor type and their required range, resolution and accuracy pending on mechanism topology.

In order to maintain the universal MCE approach despite this adaptation need, it has been decided that specific Actuator Boards, carrying the motor amplifier(s) together with the sensor acquisition cirucits, will be mandatory for a universal architecture. Therefore, the interface between Core Frame and Actuator Frame has been designed as an open architecture to ensure compatibility to any motor and sensor type.

Such different Actuator Frames are now characterized by the motor type / electrical parameters and by the type of sensors used in the mechanism. Once an Actuator Board has been developed and qualified for such a combination, re-use of this Actuator Frame design for other mechanisms with the same or a similar configuration is guarateed due to the control loops being held under software control. Presently, Actuator Frames are in design and commissioning for

A. 2-phase Stepper Motor application (range 10-50 Ω / 10-100 mH) with Hall Sensor / Switch / Potentiometer sensors
B. 3-phase Brushless-DC Motor application (range 5-15 Ω / 15-50 mH) with digital serial optical encoder

Further mechanism characteristics can be adapted by development of the respective Actuator Frames, the open architecture allows quick response time for any type of mechanism / sensor system.

Figure 6 shows the concept of different actuator frames with their standardized electrical and mechanical interface to the Core Module.

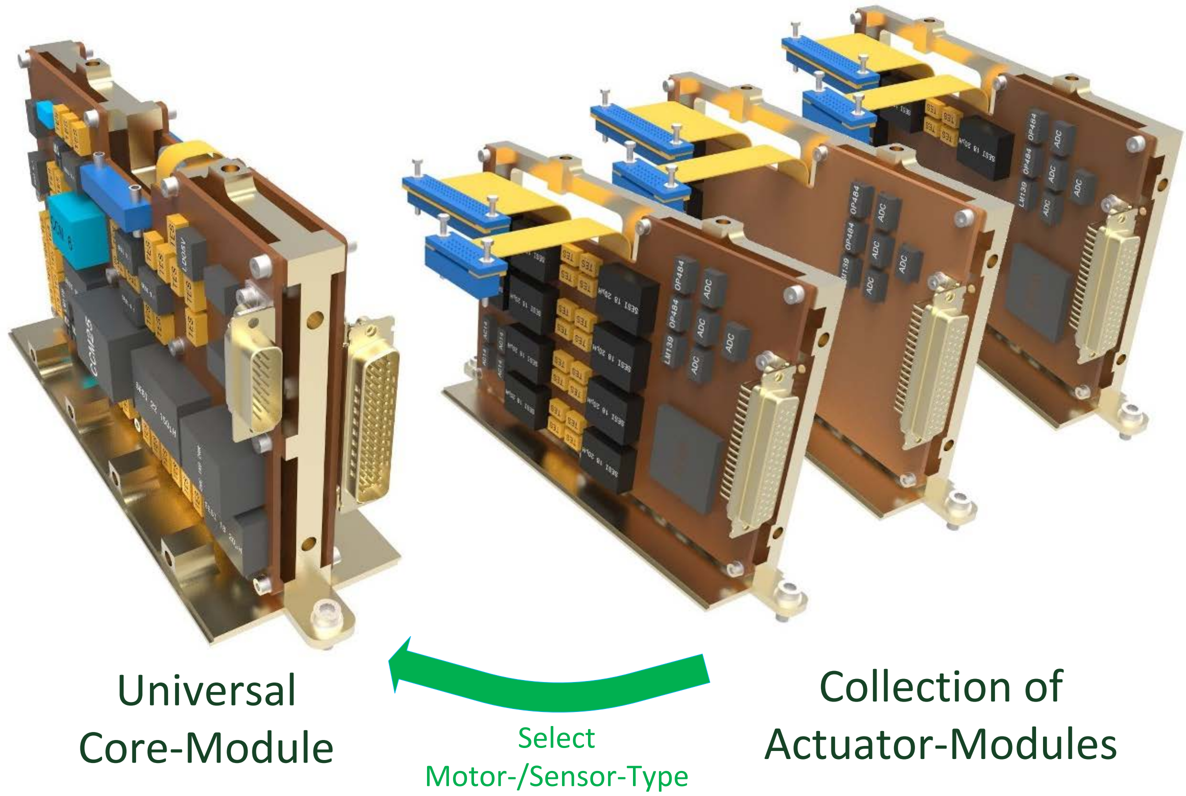

Figure 6: Different Actuator Frames can be connected to the universal Core Module

Application Summary and Conclusion

The concept for the Universal Mechanism Control Electronics and its development has been performed at Airbus Defence and Space GmbH supported by the German Space Agency (DLR). The combination of a Core Frame provides a universal primary power interface and sufficient processing power for most mechanism applications. Together with standardized control/data interfaces and mechanism characteristics, the goal to serve a high number of different mechanisms with one architecture has been sucessfully reached. The universal MCE provides a platform that can be configured in short term in software / parameters and by adaptation of the approriate Actuator Frame. Figure 7 shows the workflow for adaptation of the universial MCE to mechanism types and mechanism characteristics.

Development Status and First Integration Results

Two models of the universal MCE have been built using the developed technology. One of these models concentrated on validation of electrical design and performance validation with BLDC and DC motors in different control loop scenarios.

The second model already implements the mechanical modular architecture in the final MCE housing, the environmental analysis for thermal, structural and radiation have been performed on this model. Control Loops for BLDC and DC motors in complex motion profiles have been tested successfully and the first demonstration of these models with different mechanism types is planned for the AMS 2020 symposium.

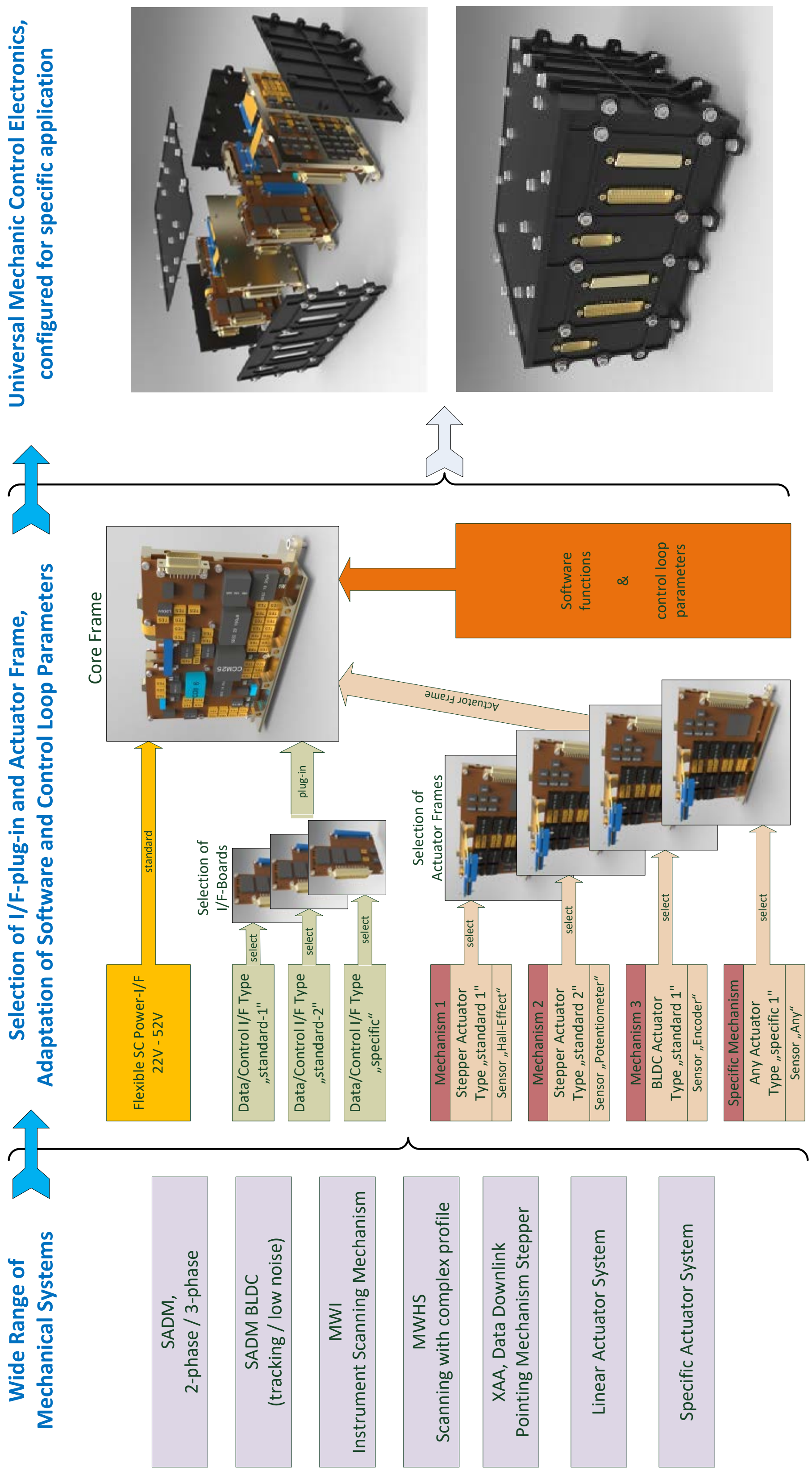

Figure 7: Adaptation flow of Universal MCE to mechanism targets