ICEPAP: AN ADVANCED MOTOR CONTROLLER FOR SCIENTIFIC APPLICATIONS IN LARGE USER FACILITIES

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Abstract

Synchrotron radiation facilities and in particular large hard X-ray sources such as the ESRF are equipped with thousands of motorized position actuators. Combining all the functional needs found in those facilities with the implications related to personnel resources, expertise and cost, makes the choice of motor controllers a strategic matter.

Most of the large facilities adopt strategies based on the use of off-the-shelf devices packaged using standard interfaces. As this approach implies severe compromises, the ESRF decided to address the development of IcePAP, a motor controller designed for applications in a scientific environment. It optimizes functionality, performance, ease of deployment, level of standardization and cost. This device is adopted as standard and is widely used at the beamlines and accelerators of ESRF [1] and ALBA [2].

This paper provides details on the architecture and characteristics of IcePAP as well as examples on how it implements advanced features. It also presents ongoing and foreseen improvements as well as introduces the outline of an emerging collaboration aimed at further development of the system making it available to other research labs.

INTRODUCTION

One of the particularities of synchrotron radiation facilities, due to the impossibility of manipulating or steering photons with electric fields, is the extensive need of mechanical positioning devices. The X-ray beams can only be steered or focused by moving or scanning optical elements and most of the instrumentation, from slits and filters to sample stages and detectors, has to be accurately positioned with respect to the beam path.

In a large hard X-ray facility such as the ESRF where remote control is mandatory because of personal safety considerations, there are thousands of position actuators, most of them motorised, involving a wide range of technical requirements that go from very simple static alignment to quite demanding control needs. Examples of advanced features are high resolution positioning in the nanometre range, synchronisation of multiple axis motions through arbitrary space coordinates, or advanced regulation modes sometimes referred to physical variables that are external to the position control system. Other demanding features include for instance precise recording of motion trajectories or on the fly triggering of data acquisition sequences in coordination with predefined positions of a mechanical device.

Selecting the motor controllers and defining an adequate deployment and usage strategy that satisfies all those requirements, often many of them simultaneously, with the high degree of standardisation and the sufficient implementation flexibility desirable at a large user facility is not an easy task. The most frequently adopted strategies are based on the use of a combination of several off-the-shelf motor control devices and modules that are packaged using standardised connectors and interfaces.

This kind of approach, that was the one adopted initially at the ESRF, is an effective solution but it unavoidably implies severe compromises in most of the aspects of the problem. That is why after fifteen years of experience and based on it, the ESRF decided to address the development of a motor controller specifically designed to optimise simultaneously functionality, performance, ease of deployment, level of standardisation and cost. The result of such an effort is the IcePAP motor controller, developed in collaboration with ALBA, and that has been adopted as standard and used extensively at the beamlines and accelerator of both facilities.

This paper provides details on the architecture and technical features of IcePAP. We also present ongoing and foreseen developments of the system, and give the outline of an emerging collaboration - on IcePAP - between several labs and institutes.

ICEPAP MOTOR CONTROLLER

IcePAP was conceived to address two somehow competing objectives; on one side to deal with high end applications that require advanced functionality and therefore must be equipped with rich hardware resources. On the other side to be used in large quantities as a basic standard motor controller appropriate for much less demanding uses and therefore requiring low cost.

Combining simultaneously these two aspects has been possible by developing IcePAP in-house based on high quality components, with reliability and high functional performance in mind and because the production of the hardware relies on direct outsourcing to electronics manufacturing suppliers.

IcePAP was specified and then developed as a “driver-centric” system able to drive different types of motors with rich built-in trajectory generation capabilities that allow for instance advanced homing modes, or the generalisation of closed loop with stepper motors. Multi-

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axis features are achieved by synchronising drivers under various possible synchronisation schemes.

IcePAP is flexible and can be considered "generic", as it can drive more than 90% of the motors at ESRF and ALBA. It is configured through a rich set of parameters that are fully programmable via a dedicated software tool called IcePAP CMS. This, in addition to the use of a standardised cabling scheme, helps to make IcePAP particularly easy to install and maintain.

ICEPAP ARCHITECTURE

Overview

An IcePAP system is built of 3 main hardware components: a power rack; the controller board (one board per rack) and the driver board (one per axis and up to eight per rack), see Figure 1.

Up to 16 racks (i.e. 128 axis drivers) can be linked together in a single IcePAP system. A system has a single interface with a host control computer through the master controller board while an internal field bus and a few synchronisation signals are shared by all the boards in the system.

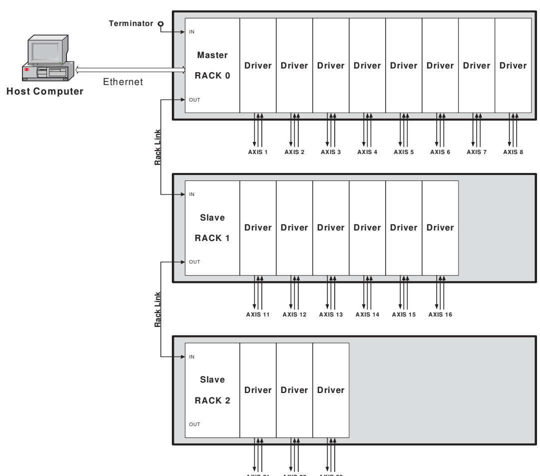

Figure 1: Architecture of an IcePAP system.

IcePAP Rack

This element - see Figure 2 - provides mechanical support for the boards. It consists of a standard 4U 19-inch rack that hosts a 1 kW power supply with power factor correction. To ensure a high reliability of the system, the back plane is equipped with good quality shielded metallic connectors for motors and encoders.

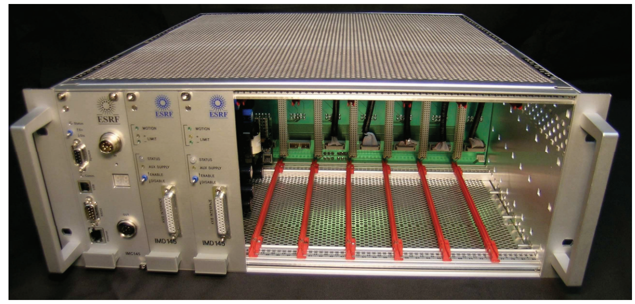

Figure 2: Partially equipped IcePAP rack.

Driver Board

This component is a DSP based high performance single-axis controller. The driver provides a flexible motor power supply: the motor current is configurable and the voltage of motor supply rail is programmable.

Each driver in a system has synchronisation capabilities: internal signals shared with the other drivers present in the system and a few external in/out synchronisation lines.

The structure of the driver is such that all hardware resources are accessible through programmable devices and therefore the hardware is fully configurable by software. The configuration, settings and positions are permanently stored in a non-volatile memory.

Controller Board

Each IcePAP rack requires a controller board of one of two types: "Master" or "Slave". Each system requires one Master controller board and accepts up to 15 Slave controllers.

The Slave controller executes rack specific functions such as the initialisation of the rack drivers, the multiplexing of synchronisation signals, the management of rack switches and internal signals.

The Master controller executes all "slave functions" for its own rack and also manages all the system functions such as system initialisation, synchronisation of axes, multi-axes management or upgrade of system firmware. It also embeds a Linux CPU that provides an Ethernet communication interface with external control computers.

Integration of IcePAP and Software

All the configuration of the axes is done by software (no jumpers or dip switches). As the set of configuration parameters is quite rich, a specific configuration tool IcePAP Control Management System (IcePAP CMS) allows simple configuration and installation tests from a computer.

The integration of the IcePAP on ALBA and ESRF beamlines is done through SPEC [3], basic TANGO [4] server or Sardana [5]. A common specific IcePAP library is under development.

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ICEPAP MAIN CHARACTERISTICS

Main Technical Characteristics

The main technical characteristics of IcePAP are detailed here below:

- It can drive two or three phase motors in the 50 mA to 7 A current range although the current firmware version only implements stepper motor control.
- Motor power: 200W
- Very high position resolution, even at high encoder speeds (up to 30 Msteps/s).
- Trajectory generation capabilities: linear (point to point movement with trapezoidal velocity profile); jogging (movement at a target velocity, the target value can be changed during the movement); updated move command (no wait for stop needed).
- Encoders: readout incremental and SSI absolute; 5V, 4-wire power supply available in the rear encoder connector

Some "Ease of Use" Features

Some existing features of IcePAP have been thought to ease the user's life:

- Firmware re-programmability: upgrading the firmware of hundreds of axes takes only minutes; last axis and encoder positions, as well as axis configuration parameters are preserved.
- Detailed diagnostics: IcePAP is able to produce very specific diagnostic information; systems can be inspected remotely.
- Advanced tests are possible, based on recording capabilities of the drivers: oscilloscope-like recording and triggering modes. A new motion diagnostics tool is being developed.
- Software configuration – IcePAP CMS: all the motor configuration information is stored in a database; In case of an intervention, when a board has to be exchanged, reloading the configuration is automatic.

Some "Unusual" Features of IcePAP

The IcePAP also shows some exceptional and unusual features, such as:

- Programmable motor voltage rail (5-75V): The same board can drive a large diversity of motors; low idle voltage helps to reduce power dissipation (significant characteristic for motor in vacuum)
- Arbitrary step definition: virtually unlimited internal resolution (actually 64 bits); combination of incommensurate axis encoder resolutions; sub-step resolution (for instance in advanced close loop modes)
- Two high frequency step generators for external synchronisation signals: frequency up to 30 Msteps/s; Same frequency limit for position input signals allows to work at acceptable speed with high resolution position signals (30 mm/s with nanometer resolution)
- Close integration of indexer and power driver: advanced control modes for steppers (optimised closed loop modes, possibility of torque control "brushless-like")

Other Relevant Particularities:

The way the IcePAP was designed and built allows meeting a substantially high reliability level. The breakdown rate observed at ESRF is very low (less than 5 driver breakdowns per year in the 7 years of use, with 2700 drivers in operation).

The IcePAP shows low production cost even for a high component quality and "resource rich" system. The average price is around 500€ per axis (compared to 1 to 2 k€ for commercially available drivers with similar characteristics), and that allows to generalise the use of IcePAP.

Finally, all the features described before are available in all drivers that are identical: there are no variants of the boards or extensions to add depending on the needed features. This simplifies extremely the maintenance and the stock management.

ICEPAP - ADVANCED FEATURES

The advanced functionalities of IcePAP allow the implementation of high level features, a significant number of which are already available to users. Some others are being developed and will be available in the coming months.

Available Features

- Position closed loop operation: in this mode the motor is continually correcting any difference between the desired position and the measure of an associated target encoder.
- Control encoder: a driver can compare its axis position – that could be a target encoder measure or the internal indexer position - with the value provided by an external encoder. If the difference exceeds a certain pre-configured value the driver shuts down the motor power. This functionality can be used for example when several drivers have to move in a coordinated way so that each axis can monitor that the others are also moving.
- Multi-axes synchronisation: The master board can prepare and start simultaneously a group of drivers from the system. The master controls that all the axes in the group complete their movement, and in case of problem with one axis, stops the whole group.
- Advanced home search sequences: Several inputs can be configured as the source for a position reference (limit switches, home switch, and encoder indexes). The search sequences start a movement, latch all the position registers when the reference

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edge is detected and stop the movement. The actual position can then be recalculated externally, or by the driver that can be configured to do it.

- Simple interfacing with external drivers: An IcePAP driver can be configured to generate trajectories for an external power driver (for special motors like 5-phase steppers, or high power motors out of the current range of the IcePAP). The external driver must accept control through step/direction or quadrature encoded position signals. Some in/out signals can also be configured to get basic information of the external driver status (power on, ready to move).
- Each driver board has three generic purpose configurable output signals that can be used in a variety of applications (control of brakes, hardware interlocking of movements, etc).

Soon Available Features and New Improvements

The features described here below are under development.

- External measure regulation: the IcePAP axis position automatically changes in order to keep a certain measure at a specified value. The measure source can be any encoder input, or a software provided value. No simple link between axis position and target measure value is assumed (only requirement is a monotonous relationship)
- Linked Axes: One single degree of freedom with several axes. The control system sees only one "virtual" axis. The master controller board monitors the axes concerned and keeps them aligned even in the case of a problem in one of them
- Electronic Cam feature: an output synchronisation pulse or level can be issued either at given position intervals or at positions predefined in a list loaded into the driver. This provides a good way to synchronise detectors with axes position without the need of any other hardware
- Movements controlled by external signals: A special movement command allows delaying the motion until it is triggered by an external hardware signal.
- Limit switch configuration modes: to simplify installation and cable testing: a) sticky switches (any switch that was hit remains activated) allow to test proper cabling of the limit switches even when the IcePAP is installed far from the equipment under test. b) smart switches: any motion in this mode is stopped whenever any limit switch is hit, so the user does not need to know which way the motor will really move.
- Parametric trajectories: A parametric table describing a curve (positions versus parameter position) is loaded into each driver. Parametric movements are then possible from one value of the parameter to another. Velocity and acceleration (time derivatives of the parameter) can be specified for each movement without having to change the table. Parametric curves in N-dimension space are possible using the existing multiaxes capabilities of IcePAP. Each of the concerned drivers has to have tables relating their position to the same parameter.
- Additional motor types: The existing hardware allows driving DC-brushed, 3-phase stepper, 3-phase synchronous and brushless motors. Future firmware versions will support all these motor types.

AN EMERGING COLLABORATION

To make IcePAP available to other research labs, and in order to foster new developments of the system, the ESRF has initiated a collaboration gathering interested partners.

The Members of the Collaboration are authorized to procure their own IcePAP systems, benefit from access to existing production documentation and also participate in the definition of the future development lines of the IcePAP project. The partners can undertake developments of new features of the system, potentially in partnership with other Members.

The Collaboration is being set up and initially rallies ALBA, MAX IV and the ESRF.

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