REVOLUTION AT SOLEIL: REVIEW AND PROSPECT FOR MOTION CONTROL

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Abstract

At any synchrotron facility, motors are numerous: they are the significant actuators of accelerators and the main actuators of beamlines. Since 2003, the Electronic Control and data Acquisition group at SOLEIL has defined a modular and reliable motion architecture integrating industrial products (Galil [1] controller, Midi-Ingenierie [2] and Phytron [3] power boards). Simultaneously, the software control group has developed a set of dedicated Tango [4] devices. At present, more than 1000 motors and 200 motion controller crates are in operation at SOLEIL.
Aware that motion control is important in improving performance, given that the positioning of optical systems and samples is a key element of any beamline, SOLEIL wants to upgrade its motion controller in order to maintain the facility at a high performance level and be able to respond to new requirements: better accuracy, complex trajectory and coupling multiaxis devices such as hexapods. This project is called REVOLUTION (REconsider Various contrOLlers for yoUr moTION).

CONTEXT AND HISTORY

Since 2003, the Electronic Control and data Acquisition group at SOLEIL has defined some standards (products and technologies) for motion control in order to provide high level support and maintenance while reducing costs.
One guideline is to prefer integration of industrial products rather than in-house development.

The challenge is to convince our internal customers that SOLEIL's motion control system can meet their specific needs with a ready solution.

The first implementation of this motion control system was done on LUCIA [5]; the first beamline of Soleil that was temporarily located in SLS [6] in late 2003. The first hardware and software prototypes were tested and debugged very early.

HARDWARE ARCHITECTURE AND PRODUCTS

To be modular and flexible, the hardware architecture of the motion control system is based on the following two principles. First the separation of control unit and power units, and then the use of standard signal exchanged between units, like a nerve impulse exchanged between the brain (control unit) and muscles (power unit). The motion units are packaged in a 19" rack that integrates industrial products. These racks specified by SOLEIL have the objectives of being easy to use, easy to maintain and cost-effective.

CONTROLBOX (the brain) integrates the Galil DMC-2182 8-axis industrial motion controller and provides easy to use connectors.

DRIVERBOX (muscles) integrates up to 8 Midi-Ingénierie boards dedicated to stepper motors.

VACUUMBOX (muscles) integrates Phytron power and control temperature boards, and is dedicated to stepper motors running in a vacuum.

SERVOBOX (muscles with a bit of mind) integrates a power board developed by SOLEIL and based on an Elmo [7] component: a numeric amplifier which manages a current loop. ServoBox is dedicated to servo motors (brushless and direct current). The prototype was validated in 2011

Today SOLEIL has standard hardware boxes able to control several kinds of motor: bipolar 4 phase stepper, brushless and DC. Theses boxes are also able to read several type of encoder: incremental (RS422/TTL signals), resolver, absolute SSI, and absolute analog.

Furthermore the flexible architecture could be connected to other technologies like 3 or 5 phase stepper motors, ceramic (piezo) actuators or sin/cos encoders via an interpolator.

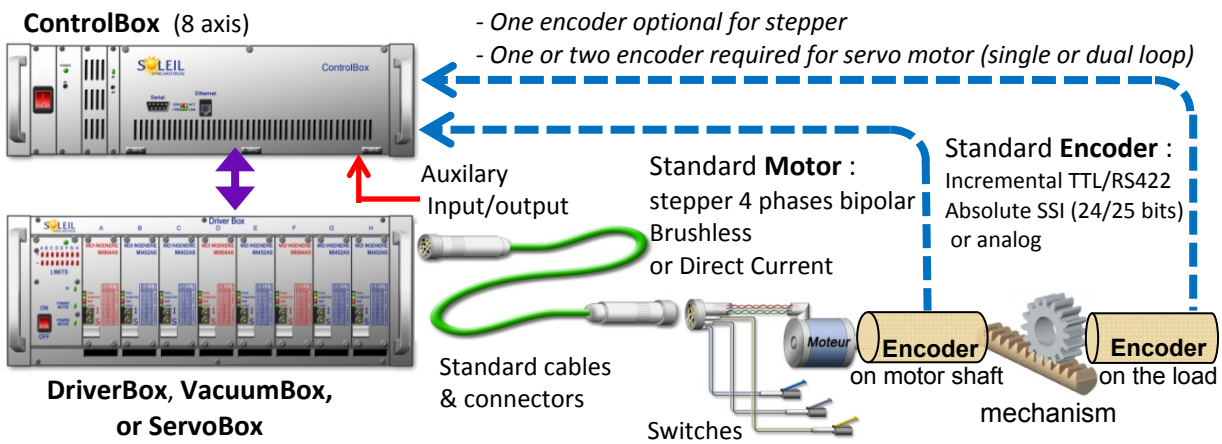

Figure 1 : Hardware architecture, standardized technologies and products.

To extend the range of supported technologies and add new features, a few years ago SOLEIL developed a flexible encoder tool in a SOLEIL proprietary format board [8]. The processing of encoder signals by a FPGA is used by example for encoder protocol transfer, encoder signals adder, complex trigger, etc.

SOFTWARE ARCHITECTURE: MULTI-LAYER PROCESSING

Motion control features are shared between embedded software in motion controllers and Tango [4] devices distributed on many servers.

Embedded Software in Motion Controllers

The firmware is provided by the controller manufacturer: Galil. It includes options for SSI encoders and for specific control loops dedicated to ceramic motors.

The microcode is developed by SOLEIL in a Galil proprietary language. Its first feature is to manage data exchanged with Tango device servers, including concentration of data and filtering all access by the device to the hardware functions. The second feature is to embed low-level motion processes as a discontinuous closed loop for stepper motors with backlash and progressive approach, static and dynamic error compensation, a multi-sensor homing process, and so on.

Theses functionalities can be completed by specific processes dedicated to specific applications especially for security of equipment. For example:

- Speed loop for phase control of RF cavities.
- Limitation of the range of 3-axis tripods according to the signals of inclinometers.
- Management of the ratio between powered and rest time of ceramic motor under vacuum.
- Limitation of the difference in position between 2 axes of a mirror bender.
- Collision avoidance according to security equations of multi-axis positioners.
- Etc.

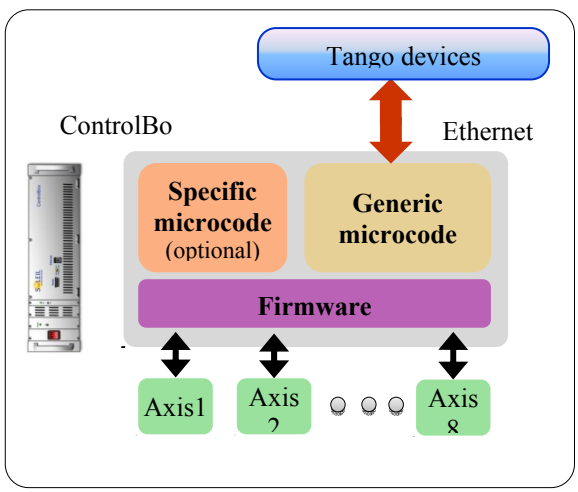

Figure 2: Embedded software architecture.

SOLEIL Motion Control Tango Devices Server

A set of motion control Tango device servers dedicated to our motion controllers has been developed in C++ by SOLEIL's Software Control and data Acquisition group. Binaries can run on Windows or Linux server.

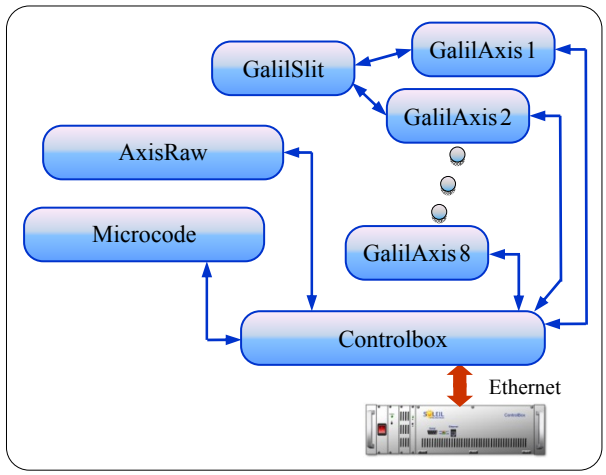

Figure 3: Tango devices servers architecture.

The lowest level and most essential device server is called ControlBox. It manages communication with hardware by TCP/IP protocol and provides data used for other devices. The GalilAxis device is a software object which represents a real motor. The device interface (properties, attributes and commands) is limited to simplify use. Multiple configurations and complex settings are hidden and not directly accessible to this software level. The GalilSlit device manages a pair of axes and supervises the master/slave relationship managed by hardware. It offers Gap and Offset attributes. The AxisRawDataReader device is a specialist device. It provides expert data from hardware, such as Tango attributes (read/only). Finally the MicrocodeDataViewer device provides access to variables of specific microcodes. It is used for supervision.

CURRENT RESULTS

Quantitative Results

Today the installed base of standard motion control equipment is wide and quite homogenous. It is broken down to around 15% for the machine and 85% for beamlines. As of May 2011, 1183 stepper motors controlled by 220 ControlBox and roughly as many DriverBox or VacuumBox units are operational at Soleil.

Furthermore 107 non-standard axes, like stepper 5 phases, ceramic and brushless motor (installed before ServoBox was in operation) are driven by 35 non-standard power racks, but they are controlled by ControlBox.

However, this is not the case for all motors. 37 mechanical devices with 244 axes are fully non-standard. They are mainly distributed in motorized magnetic insertion devices, diffractometers and hexapods. The reasons for this non-standard hardware, are firstly because

the control group did not have an effective solution when the equipment was chosen and also that manufacturers refuse to guarantee the performance of equipment if their own motion control system is not used.

Qualitative Results

Currently the initial objectives have been achieved and the motion systems work. Costs are controlled. There is no delay in providing working systems. The hardware components are reliable. Very little equipment is returned to the supplier. Software is efficient and reliable. Interventions relating to motion control during operation are very few. Performances are sufficient today for almost all applications.

Standardization has been largely successful. However, do not fall asleep and remember that future results get ready today: the revolution is coming…

MOTION CONTROL PROSPECTS: A REVOLUTION

Need to Upgrade: Birth of a Revolution

Firstly Galil released a new generation of motion controller (Accelera products) in 2009, so our standard controller belongs to the previous generation and has been produced for 8 years. It will be discontinued in a few years, but when?

Secondly, new motion control applications become more complex and demand more performance. Some examples:

- Hexapod platforms are more and more used in radiation facilities. They require control of complex multi-axis trajectories and calculation for kinematic equations.

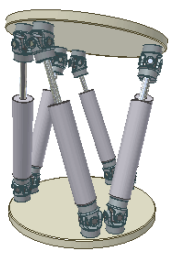

Figure 4: View of Stewart Hexapod platform.

- Nanopositioning: be able to position an axis to within few nanometers and keep this position by compensating for external disturbances, by using external sensor (e.g. interferometer). This requires fast and powerful calculations and openness to new technologies.
- Synchronization: be able to synchronize several axes and sensors to perform a continuous scan over complex trajectories. This requires fast signal processing calculations

So in the future, to preserve the use of standardized products, these products need to be improved. That means the next standard controller must be faster and more powerful in calculation and provide new features. SOLEIL must consider the next standard controller today.

A Technical Collaboration and a Founding Event

MAX IV [9] is the next Swedish radiation facility. The construction has just begun, the first beam is planned in 2015. MAX IV needs to define an up-to-date motion system architecture and select a controller quickly and efficiently.

SOLEIL and MAX IV have similar motion controller requirements: reliable, high performance and flexible, and they have similar guidelines too: minimal or no in-house development, standardization of hardware, modular solution, ready to use and complete solution

Consequently SOLEIL and MAX IV started a new technical collaboration to work together on this. This collaboration is called REVOLUTION, an acronym of REconsider Various contrOLlers for yoUr moTION.

In mid May 2011 SOLEIL and MAX IV organized a workshop "Exchange around motion control in radiation facilities". It was the founding event of the REVOLUTION project. 20 participants from 7 European facilities discussed an overview of motion systems in synchrotron facilities: status, main issues and plans

Figure 5: Map of radiation facilities participating in the motion control Workshop in May 2011.

The main results of the workshop are a written summary of thoughts [10], a creation of a dedicated mailing list "MOtion control Community in RAdiation Facilities" [11] and a principle of organizing a workshop every second year. The next motion control workshop will be hosted by the DIAMOND [12] facility, in the UK.

Some Guidelines of the REVOLUTION

The REVOLUTION's objective is to provide a complete ready-to-use solution for motion control. The main steps and deliveries of the project are clearly defined. The first and essential step is the selection of an industrial motion controller as a new standard. This controller will be integrated into a crate. After the design of the crate, an industrial company will be selected to manufacture it.

Another significant part relates to software developments: embedded software in the controller and Tango devices. The last step is about technical training for staff and writing technical documentation

The scoping of the project defines Rebox as the name of the next motion controller together with its crate. The capacity to replace any ControlBox by Rebox, and therefore backward compatibility of technical specifications (e.g. connectors) is a major principle. Finally the new features expected of the Rebox are set in the short, medium and long term (e.g. support of sin/cos encoder signals, extended auxiliary internal or remote I/O, etc.).

CONCLUSION AND PERSPERCTIVES

Although based on positive results in quality and quantity, the need for improvement of motion control systems is essential to maintain the SOLEIL facility at the highest level of performance. This need to obtain an efficient, complete and ready to use system is shared with the MAX IV facility under construction. REVOLUTION, the technical collaboration born from the common need will share costs and good ideas.

REVOLUTION is already underway. Starting from the motion control workshop, through the loan of equipment and skills with Swedish partners and continuing with a study of available controllers and detailed evaluation of some, the road is still long but major steps are defined to achieve the goal.

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