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GeCo: THE ELETTRA 2.0 BEAMLINE CONTROL SYSTEM

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Abstract

The Elettra Synchrotron, located in Italy near Trieste, has been operating for users since 1994 being the first third generation light source for soft X-rays in Europe. To stay competitive for world-class photon science, a massive upgrade of the storage ring has been planned in 2025. The goal is to build an ultra-low emittance light source with ultra-high brilliance in the same building as the present storage ring. The downtime for installation and commissioning of Elettra 2.0 will last 18 months. In this plan, 20 of the present beamlines should be upgraded and 12 new beamlines are scheduled to be built. In this scenario, also the original beamline interlock and personnel safety systems are going to be upgraded using state of the art technologies. Siemens PLCs will be used for low level control, while higher level applications will be developed using the Tango framework. This work presents and describes the architecture of the future Elettra 2.0 beamline control system named GeCo, Gestione e Controllo in Italian.

INTRODUCTION

Elettra-Sincrotrone Trieste is an Italian non-profit company of national interest that manages a multidisciplinary research centre with two light sources: the 3rd-generation synchrotron source Elettra, in operation since 1993 [1], and the seeded free-electron laser source FERMI, in operation since 2010 [2]. The light from Elettra feeds 28 beamlines with experimental stations that offer access to state of the art instrumentation for the most advanced spectroscopy, scattering and imaging techniques.

After nearly 30 years of operation, the Elettra synchrotron radiation source will be replaced by the new Elettra 2.0 4th generation light source. The Elettra 2.0 storage ring will employ a symmetric six-bend enhanced achromat lattice and will operate predominantly at 2.4 GeV. The brightness will increase ~ 35-fold at 1 keV and ~ 160-fold at 10 keV. The coherent fraction is expected ~ 30% and ~ 3% at 1 and 10 keV, respectively. These parameters of Elettra 2.0 will boost the spatial, energy and temporal resolution of all the experimental end-stations. The project is ongoing and the new storage ring and the first beamlines should start operation in 2026.

Elettra 2.0 will have up to 32 beamlines (Fig. 1): 20 of the present ones should be upgraded, and 12 new are scheduled to be built. For all of them a new control system infrastructure has been designed using state of the art technologies. The project involves the Interlock System, the Personnel Safety System and the Instrumentation Control System. The next sections provide the reader with a technical overview of the new beamline interlock system GeCo, a highly optimized and smart solution that allows to operate on the beamline components and the vacuum elements in safe conditions.

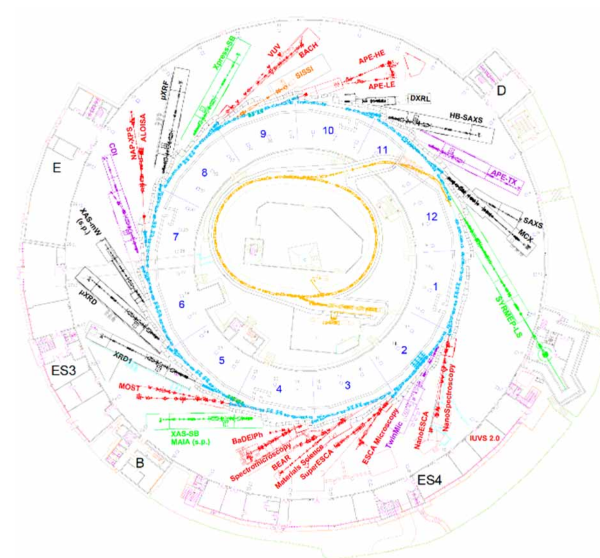

Figure 1: Elettra 2.0 beamline layout.

GECO INTERLOCK SYSTEM

Introduction

The present beamline control system (BCS) is based on VME industrial PCs running a LynxOS real time operating system. Beamline instrumentation is interfaced through digital and analog I/O boards or via serial or Ethernet communication protocols. The BCS is written in C language and is composed by a set of software drivers and a configuration ASCII database. It implements software interlocks and automatic actions that allow to operate the beamline components in safe conditions.

The BCS system has proven to be robust and reliable but, after almost 30 years, it suffers from obsolescence problems and a lack of spare parts. The new beamline interlock system GeCo, based on PLC (Programmable Logic Controller) technology, is the natural evolution of the present system. It has been designed and built to directly control the existing beamline components, getting rid of obsolete interface tools. Its name derives from two Italian words: Gestione (management) and Controllo (control).

Hardware Description

Each GeCo interlock system is based on a master PLC (Siemens S7 1500 – CPU 1513 - 1PN) and one or more peripheral slave units (Siemens ET200MP - IM155-5 PN ST3-1). A specialized 6U crate has been engineered in-house for hosting the PLC instrumentation (Figs. 2 and 3).

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Particular attention was paid to the optimization of the internal and external cabling.

Figure 2: GeCo crate front view.

Figure 3: GeCo crate rear view.

As common cabling strategy, the instrumentation signals along the beamline are grouped in passive junction boxes, such boxes are connected to the backplane of the PLC crate via a multi-wire pin-to-pin cable. The GeCo backplane has been designed in order to be populated with standard, easy to manage interface modules (Fig. 4). The internal cabling has been simplified by using industrial connecting interfaces and pre-assembled cables so that the wiring time is significantly reduced.

Four categories of beamline devices have been identified: vacuum valves, alarms from pressure gauge controllers or ion pumps, flow switches and thermocouples. For each category exists a specific junction box, multi-wire connection cable and backplane I/O module. The use of such standards significantly reduces the installation time during the upgrade process, in fact all the necessary items could be prepared and assembled in advance. Furthermore, in the near future a set of standard spare parts will be available for minimizing the down time in case of faults.

Figure 4: GeCo analog and digital interface modules.

Interlock System Topology

The GeCo system is composed by a PLC master and one or more peripheral slaves. They are connected via PROFINET fieldbus, while a network communication module on the master unit (Siemens CM 1543–1) allows software clients to interact with the system using a Modbus protocol (Fig. 5).

The operational field of the master unit includes the vacuum and beam transport elements of the initial common part of the beamline (front-end included). It is also directly connected to the Personnel Safety System (PSS) for controlling the safety radiation shutter and stopper. The peripheral slave units are used for controlling the vacuum and beam transport devices on the branch lines.

The number of cables is significantly reduced by the use of the junction boxes, policy that allows to prepare in advance most of the needed cables and their installation becomes faster and easier.

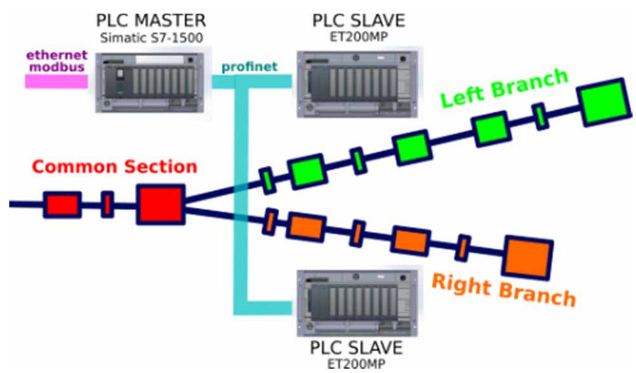

Figure 5: GeCo system topology.

Software Description

The GeCo PLC firmware has been developed with the Siemens programming tool Tia Portal© [3], using the Structured Control Language (SCL). The starting point is a template project, suitable for every beamline, which gets customized on the base of the interlock rules. The template project contains a library of function blocks, a set of pre-defined data structures and a set of tag tables.

Before starting to write the software a deep analysis of the beamline devices and sensors is performed in collaboration with the Vacuum Group, responsible for the drafting of the interlock rules. Every element is named following the internal naming rules of the Elettra 2.0 project. This result of this procedure is an Excel file containing a full description of all the signals involved in the interlock system. A set of Python scripts is then used to parse this Excel file and automatically produce the I/O tag table used by the PLC program. In fact the result files produced by the scripts can be imported in the Tia Portal project, saving a significant amount of time and human errors.

One of the fundamental elements of the PLC software is the Modbus Data Block used for the communication with the external client programs. This Data Block has been designed with a smart self-describing structure (Fig. 6) and contains, cycle by cycle, a snapshot of the status of all the

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controlled elements. The Data Block has a header section with a fixed structure: part of it is dedicated to the external command communication, the rest to a FIFO log queue. The rest of the Data Block depends on the beamline setup and contains a set of data structures reporting the current status of all the sensors and actuators. A set of pre-defined data structures associated to each type of controlled component has been identified:

- vacuum valves
- vacuum alarms
- temperature sensors
- position sensors
- water flow meters
- water flow switches
- fast valves
- interlocks

Each component in the Data Block is identified by an incremental index and reports its actual value and some metadata information like the type, the name, the thresholds, etc. The index of the component is a key information used both in the logging system both in the external command protocol.

CLIENT COMMAND	String
COMMAND RESULT	String
CFG REF DATE	Date
LOG MESSAGE LENGTH	Int
LOG BUFFER LENGTH	Int
LOG BUFFER	Array [String]
DATA BLOCK START	-1
COMPONENT1	Data Struct
COMPONENT2	Data Struct
COMPONENT3	Data Struct
...	...
DATA BLOCK END	-2

Figure 6: GeCo Modbus Data Block structure.

Thanks to this smart self-describing structure it was possible to develop a single client program suitable for every installation. In fact any Modbus client program with a dynamic structure can easily parse this buffer and adapt itself to it.

Particular attention was given to management of the log messages queue that has been implemented with a circular FIFO log buffer, used for tracking any meaningful event like a detected harmful condition or the execution of an external command. Log messages are composed by a time reference, a pre-defined event code and the index of the involved component. The Modbus client can periodically retrieve the log queue content, decode and archive it to a log file.

SOFTWARE TOOLS

GeCo Tango Device

The control and data acquisition system at Elettra and FERMI is based on the Tango framework [4]. A new Python Tango device server has been developed for integrating the new GeCo interlock system. At startup, after the initialization of the Modbus connection to the PLC, the device server reads and parses the content of the data exchange Data Block. A dynamic attribute is then created for each element listed in the Data Block. This set of attributes gives a snapshot of the acquired sensor values and is continuously updated by a periodic readout of the PLC buffer Data Block. Thanks to this automatic configuration there is no need to develop a new Tango device server for each GeCo installation or when a beamline setup is modified.

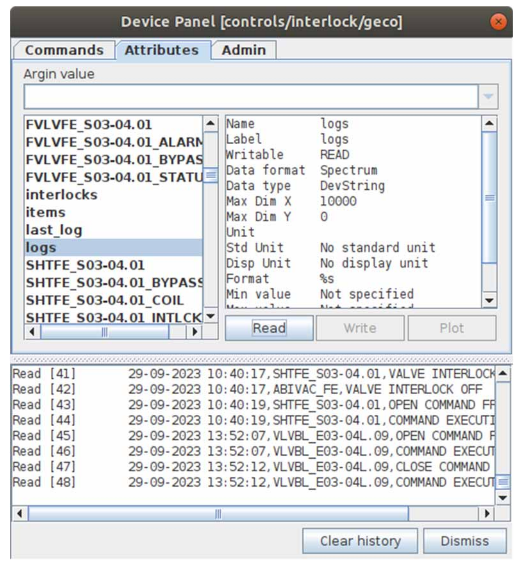

Figure 7: GeCo Tango device server.

Beside these dynamic attributes, the GeCo device server (Fig. 7) instantiates and updates a set of pre-defined spectrum attributes:

- logs: list of log messages, also stored in log files;
- alarms: list of elements in alarm state;
- interlocks: list of inhibited elements.

Finally it exports a general method command() that is used to perform actions on the beamline instrumentation, (i.e. opening/closing a vacuum valve).

DonkiWeb, The Scripting Web GUI

The status of the existing Elettra beamlines can be monitored and controlled through a synoptic web tool called BCS Beamwatch. Behind this tool exists a custom Apache server module that is strongly integrated to the present BCS. In the whole upgrade process related to Elettra 2.0 we took the chance to introduce and test a new synoptic web platform. DonkiWeb, the new web tool, integrates a web server written in Python and a GUI Javascript library that simplifies as possible the development of graphical web interfaces.

The core multi-threaded web server has been customized in order to offer a REST interface to the Tango control system. Using a defined URL format it is possible to read/write attributes, send commands or subscribe to a data stream web-socket server.

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Static URLs and embedded REST Tango server are protected with an internal authentication method that can be configured with the client IP addresses or via user authentication. In the latter case the user credentials are checked through the authentication service offered by the Elettra Virtual Unified Office (VUO) [5].

As already introduced, DonkiWeb aims to be a fast and easy to use tool for the development of graphical web interfaces connected to the Tango control system. For this scope we developed a JavaScript library that allows to create a web interface using a simple scripting style code. The tool is based on the widgets offered by the litegui.js library [6] that permits to create web pages with a desktop look-like interface. In few lines, using the methods offered by the DonkiWeb library, it is possible to create and populate a Tango user interface with dynamic labels, buttons, dialogs, tab containers, etc.

One of the first prototypes was the summary interface for the GeCo interlock system (Fig. 8): it allows an easy access to the whole set of GeCo elements without the need of any knowledge of the Tango tools. The beamline staff, using a web browser, can operate on the beamline valves and can have visual evidence of existing interlocks, alarms and log entries.

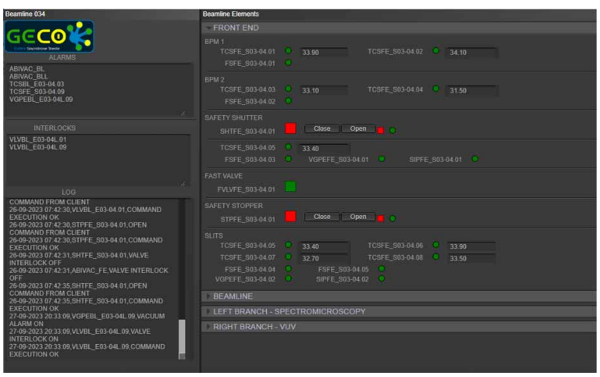

Figure 8: GeCo Web summary page.

Using the DonkiWeb library has been created also a web synoptic (Fig. 9) that visually integrates information coming from different Tango devices belonging to the beamline control system. The graphical elements and the text labels of the synoptic are automatically updated with a background web-socket data streaming.

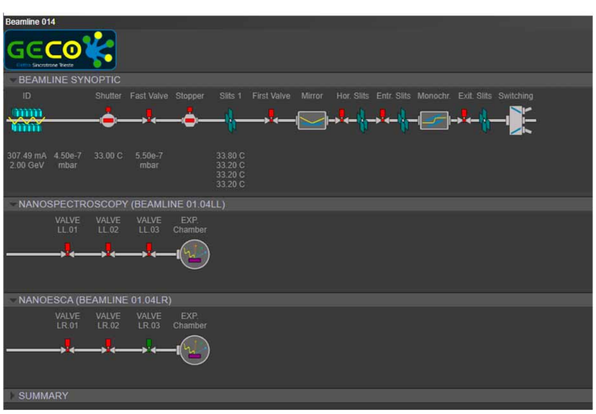

Figure 9: GeCo beamline web synoptic.

CONCLUSIONS

The installation of a new control system for 32 beamlines has been planned in the Elettra 2.0 project. In this scenario a new beamline interlock system, using state of the art technologies, has been designed and developed. The new interlock system, named GeCo, has been already installed in 2023 for controlling two beamlines with two branch-lines each.

The use of PLC technologies, with direct control of digital and analog signals, permits to get rid of obsolete instrumentation (i.e. valve controllers, analog signals monitors, fast valve interfaces, etc.). An important simplification of the cabling has been reached by using peripheral slave devices and grouping junction boxes. As a consequence of the upgrade process the number of racks in experimental hall could be considerably reduced as well as the energy consumption.

The already upgraded systems control respectively 56 and 111 elements, and manage about 20 and 40 interlocks rules. The average PLC cycle times are shown in Table 1. Even if they are completely satisfactory, a more powerful PLC processor could further increase the interlock system performance.

Table 1: PLC Average Cycle Time

Beamline	Number of Slaves	Average Cycle [ms]
BL 012	1	16
BL 032	2	30

In the near future, in addition to the beamline interlock system, there will be the need to upgrade on every beamline also the Personnel Safety System (PSS) and the whole motion system (Fig. 10). Regarding the latter, most of the motion controllers will be substituted with the YAMS motor controller [7], a standard solution for Elettra and FERMI.

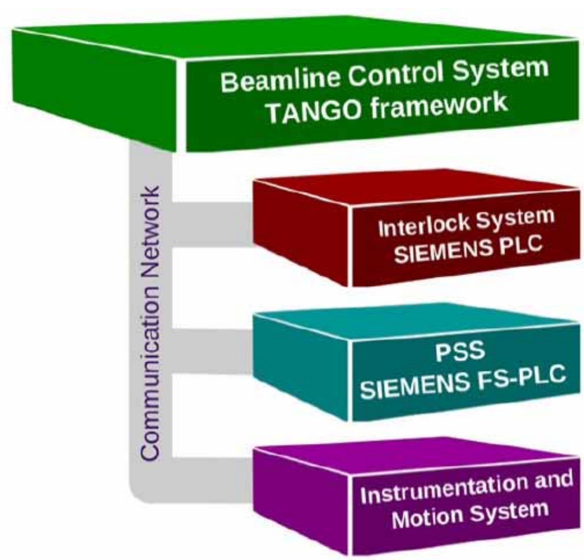

Figure 10: Elettra 2.0 beamline control system diagram.

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Also the design of the PSS is already started, it will inherit most of the hardware solutions adopted in the GeCo interlock system and will be based on Siemens Fail-Safe PLC controllers.

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