THE LASER MEGAJOULE FACILITY: CONTROL SYSTEM STATUS REPORT

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Abstract

The Laser MegaJoule (LMJ) is a 176-beam laser facility, located at the CEA CESTA Laboratory near Bordeaux (France). It is designed to deliver about 1.4 MJ of energy to targets, for high energy density physics experiments, including fusion experiments. The commissioning of the facility was achieved in October 2014. This paper gives an overview of the general control system architecture, which is designed around the industrial SCADA PANORAMA, supervising about 500 000 control points, using 250 virtual machines on the high level and hundreds of PCs and PLCs on the low level. We focus on the rules and development guidelines that allowed smooth integration for all the subsystems delivered by a dozen of different contractors. The integration platform and simulation tools designed to integrate the hardware and software outside the LMJ facility are also described. Having such tools gave us the ability of integrating the command control subsystems regardless the coactivity issues encountered on the facility itself.

LMJ FACILITY

The LMJ facility covers a total area of 40,000 m2 (300 m long x 150 m wide). It is divided into four laser bays, each one accommodating 5 to 7 bundles of 8 beams and a target bay holding the target chamber and diagnostics. The four laser bays are 128 m long, and situated in pairs on each side of the target chamber. The target bay is a cylinder of 60 m in diameter and 38 m in height. The target chamber is an aluminium sphere, 10 m in diameter, fitted with several hundred ports dedicated to laser beams injection and diagnostics introduction. Numerous diagnostic instruments are placed in the target chamber around the target to record essential measurements and observe the target behaviour during its implosion. These diagnostics are the prime tools for the physicists to determine the characteristics of the plasma under study.

LMJ CONTROL SYSTEM

LMJ Control System functions

The main functions of the control system are shots execution and machine operations: power conditioning controls, laser settings, laser diagnostics, laser alignment, vacuum control, target alignment, target diagnostics.

All these components are triggered with a high precision Timing and Triggering system [1].

The control system has also a lot of other major functions: personnel safety, shot data processing, maintenance management.

Conducting a shot is composed of two phases: first a master countdown prepares the machine and secondly an automatic sequence [3] executes the shot from the power conditioning charging to the target implosion.

The master countdown has an expected duration of about four hours and the final automatic sequence lasts a few minutes from power conditioning charging to shot execution.

The master countdown coordinates manual operations or automatic programs that prepare the machine: automatic settings computation [4] and associated downloading, laser and target alignment, diagnostics preparation. This can take 2 or 4 hours.

Then, when the laser is ready, the automatic sequence is started: the power conditioning is charged. This takes a few minutes. Then the computer system hands over to the electronic timing system that guides the laser pulses from the master oscillator sources to the target through the amplifiers and transport sections. This takes about 1 microsecond.

General Architecture

The LMJ control system has to manage over 500 000 control points, 150 000 alarms, and several gigabytes of data per shot, with a 2 years on line storage.

It is composed of a dozen of central servers supporting about two hundreds of virtual machines at the central controls level and about 450 PLC's or rack mount PC's at low levels.

Hardware Architecture

From the hardware point of view the LMJ control system is constituted of two platforms located in two different buildings:

- one for system integration (PFI), which is in operation in a dedicated building and consisting of a clone of the operational control system at the supervisory levels and a mixture of simulators and real controllers for representing low levels controls and real equipment [2].
- The operational platform, consisting of two sub-platforms: a small one for integrating the laser bundles (PI) and one for normal operations (PCI).

For each platform, two redundant Alcatel-Lucent OmniSwitch cabinets provide redundant Gigabit attachments to twelve subsystems backbones and main servers (Fig. 2).

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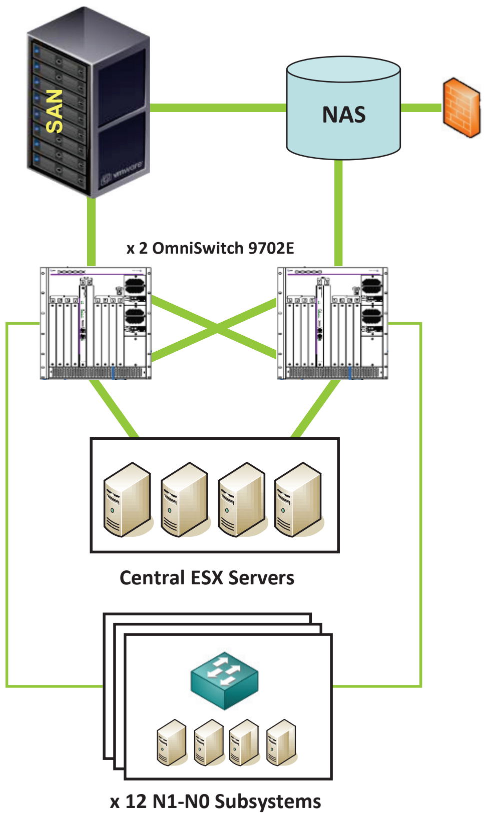

Figure 1: LMJ Network architecture.

On each platform, virtual independent contexts are configured using Virtual Routing and Forwarding technologies (VRF): on the integration platform this allows to simulate different test contexts at the same time with identical IP address spaces, and on the operational platform this allows simultaneous operation from the operational control room and the integration one.

N1, N2 and N3 layers are virtualized using VMware and DataCore solutions. Each platform consists of one virtualization infrastructures (Fig. 3) composed of:

- 2 DataCore servers, each one managing 12 To of disks,
- 6 to 8 ESX Dell PowerEdge R815 servers, with 4x12 cores and 128 Go of RAM,
- 1 VCenter Server to manage the VMware infrastructure.

Each of these infrastructures is dimensioned to execute several hundreds of virtual machines (Fig. 6).

Software Architecture

All command control software developed for the supervisory layers uses a common framework based on the industrial PANORAMA E2 SCADA from Codra.

In this framework the facility is represented as a hierarchy of objects called "Resources". Resources represent devices (motors, instruments, diagnostics…) or high level functions (alignment, laser diagnostics). Resources are linked together through different kinds of relationships (composition, dependency, and incompatibility) and the resources life-cycle is described through states-charts. Control-Points, alarms, states and functions can be attached to any resource (Fig. 1). Dedicated mechanisms manage the resource reservation and propagate properties and states changes into the tree of resources through relationships. There are about 200 000 resources in order to describe the entire LMJ.

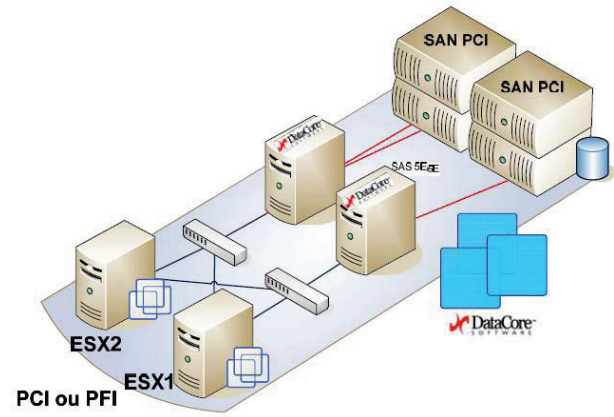

Figure 2: LMJ Virtualization architecture.

The framework implements the data model described above as .net components inside the PANORAMA E2 SCADA and adds some common services to the standard features of PANORAMA E2:

- resources management,
- alarms management,
- lifecycle states management,
- sequencing [3],
- configuration management,
- event logging

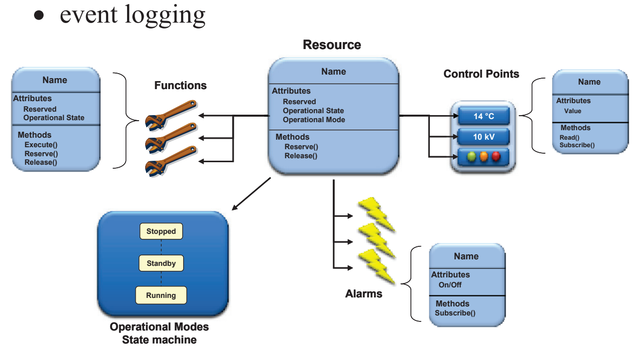

Figure 3: Data model used by the LMJ supervisory System.

INTEGRATION STRATEGY

Design of the LMJ was entrusted to a dozen of major contractors. Each one supplied all the command control associated its delivery, including the supervisory levels. CEA itself was responsible for definition design standards and subsystems integration.

To achieve that, an integration policy was clearly defined and imposed to all contractors.

This policy was based on a for steps process :

- External interface definition,
- Factory tests,

- Integration between subsystems on an dedicated platform (PFI),
- Functional integration on the LMJ facility.

External Interface Definition

Each contractor's supervisory subsystem communicates with the other supervisory subsystems and with the central one that allows to drive the whole facility and shot sequences.

All these communication interfaces between supervisory subsystems are formally defined and managed by CEA in a centralized database and exported to contractors as xml files (Fig. 4). Dedicated tools allow to automatically generate from these xml files:

- Supervisory subsystems' skeletons.
- Supervisory subsystems' simulators called SITEX, which allow contractors to simulate the external environment they are communicated with, during software development and factory commissioning.
- The device settings configuration database that contains, for each subsystem, all the settings used by shot sequences to configure laser devices and measurement instrumentation.

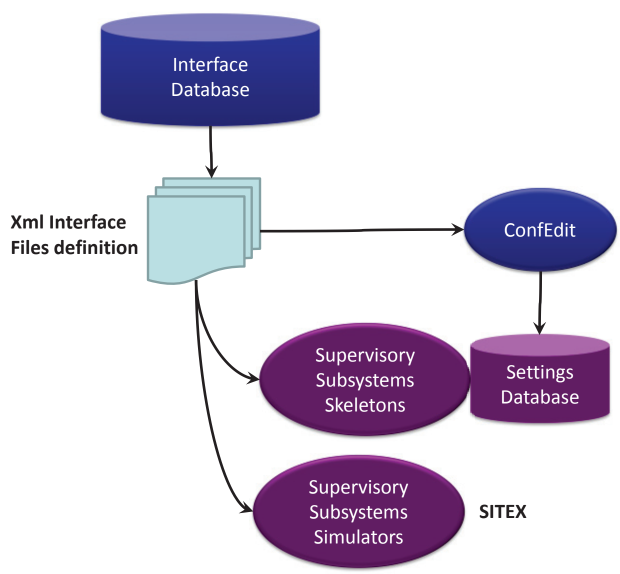

Figure 4: Software Interfaces Management.

Factory Tests

Factory tests are centered on functional requirements and have to demonstrate the ability of the supervisory subsystem delivered by each contractor to drive a full LMJ configuration (e.g. 22 bundles).

As the equipment for all bundles cannot be present at factory, this configuration must at least include a real set of equipment for one, and device simulators are used to simulate the others. These simulators also allow the simulation of abnormal behaviours that would be impossible to obtain with real equipment (safety, cost, etc.).

As it was described before, all external supervisory subsystems they communicate with, are simulated with SITEX generated and delivered by CEA from the centralized interface database.

Integration Tests on PFI

Each Subsystem Control system is delivered on the Integration Platform (PFI) and tested in three successive phases:

- Phase 1: standalone phase in which the other subsystems are simulated by SITEX (Fig. 5).
- Phase 2: integration phase in which each subsystem is connected to the high level supervisory system and the other subsystems already installed. During this phase each interface between one supervisory subsystem and the others is tested.
- Phase 3: the global commissioning phase. During this phase the global functioning is tested using all subsystems and shot sequences.

Functional Integration on the LMJ Facility

As bundle commissioning will be a long process spread over several years, a dedicated control room were designed to allow new laser bundles commissioning, while already commissioned bundles are operated for shots and fusion experiments from the main control room.

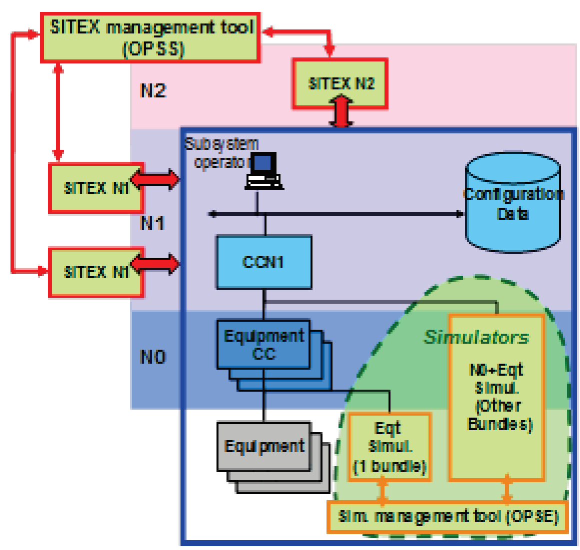

Figure 5: Different kinds of simulators used on the Integration Platform.

A second supervisory system was installed in this room and is connected to new bundles, as their commissioning is beginning. From this control room two kinds of tests are conducted:

- First, testing of each subsystem driven by the contractor which is responsible for. It is the first time that the subsystem software package controls the real equipment using the nominal wiring. In a standalone mode, with the same integration tools used at factory, the contractors check the behavior of equipment with the facility wiring.
- Then, testing of the whole bundle driven by CEA. As soon as all the subsystems are integrated on the

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bundle, CEA makes sure that all subsystems and the high level supervisory system work well together.

When this phase is achieved, the new bundle is switched to the main control room and final testing allows to demonstrate that ability of the new bundle to be operated with the others.

LMJ PROJECT STATUS

Commissioning of the first bundle was achieved on time in October 2014. The first laser target interaction experiment was done on fall 2014 and a second experimental campaign on April and May 2015. Next one is scheduled on last trimester 2015.

From the command control point of view, the integration control room was commissioned during this summer (as first bundle's integration took place in the operational control room). Next step will be to commission in fall a new version of the supervisory software with a complete 22 bundles configuration and then deploy this version in the integration control room in order to begin the second bundle's integration. This step will end the commissioning process of the command control by itself and began its maintenance phase.

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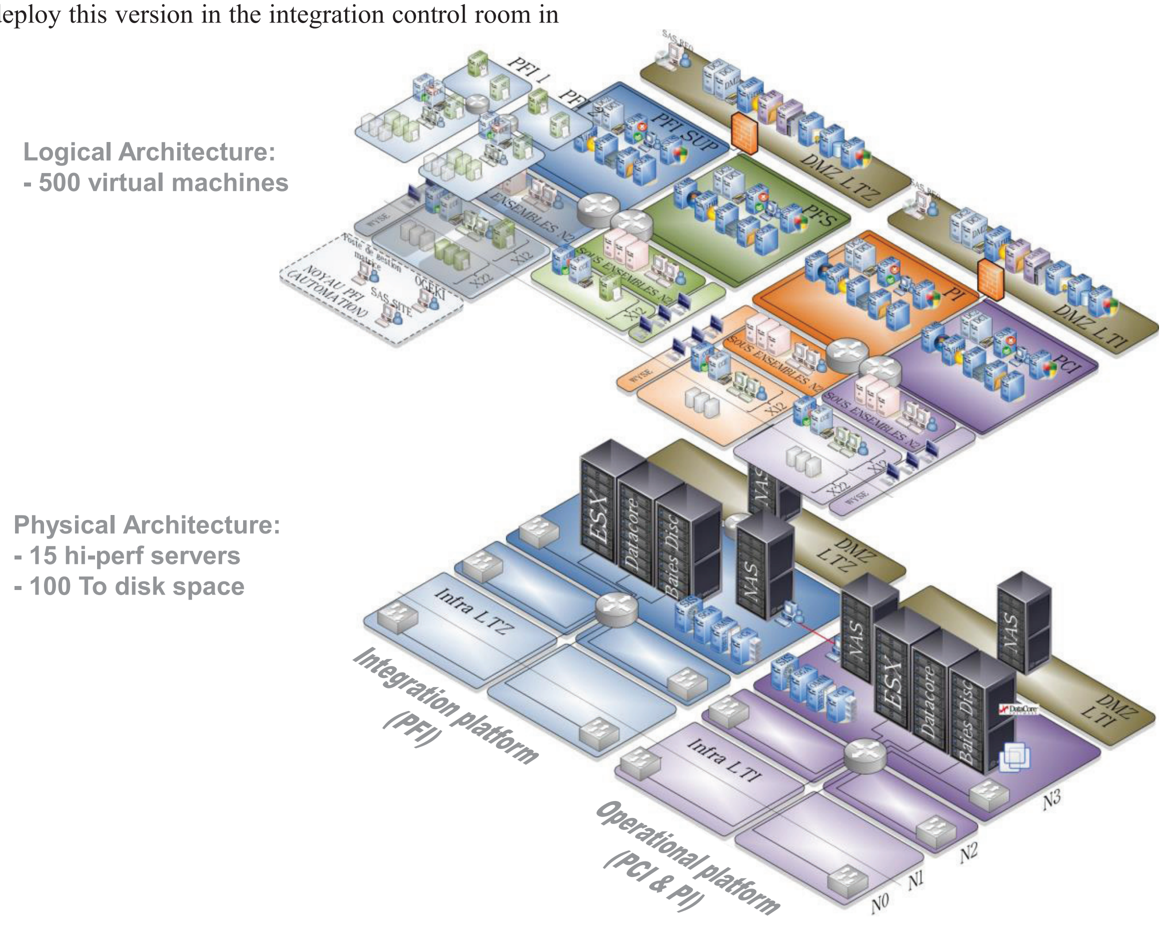

Figure 6: LMJ Central Controls Physical and Logical Architecture, showing the integration platform and the operational one.

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