THE LIGHT CONTROL AND INTERLOCK SYSTEMS

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ABSTRACT

LIGHT (Linac Image Guided Hadron Technology) is a particle therapy system* developed by Advanced Oncotherapy plc. Accelerator, control and interlock systems are developed by its subsidiary A.D.A.M. SA, a CERN spin-off. The system is being designed to accelerate protons up to 230 MeV using a modular and compact 25-meter-long linear accelerator. It is being designed to operate in pulsed mode where beam properties (energy, pulse charge and spot size) can be changed at 200 Hz.

The LIGHT product will be installed in different facilities. As such, the installations will differ in accelerator and beam transfer line layouts, number of treatment rooms (with an optional gantry), facility services, equipment suppliers and equipment versions. Thus, the control and interlock systems need to be extensible through configuration and modularization. To achieve this, the control system relies on a multi-tier architecture with a clear separation between front-end devices and controllers. To minimize time-to-market, the systems rely mostly on COTS hardware and software, including a timing and triggering system and a light-weight software framework to standardize front-end controllers.

* The LIGHT Proton Therapy System is still subject to conformity assessment by AVO's Notified Body as well as clearance by the USA-FDA

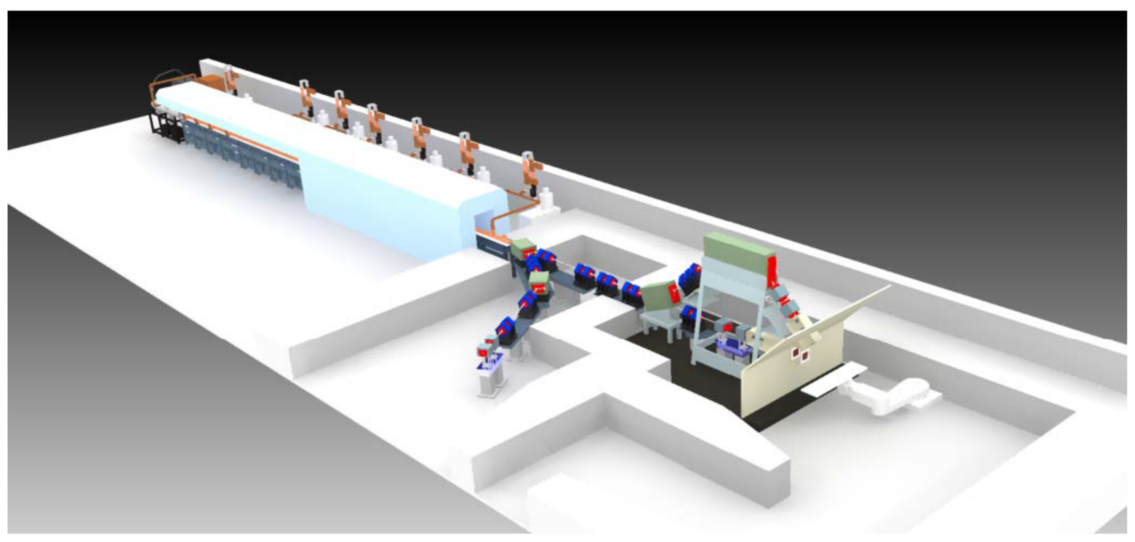

Figure 1: Example layout of LIGHT.

INTRODUCTION

ADAM S.A. is a CERN spin-off founded in 2007 in Geneva (Switzerland) developing applications of detectors and accelerators to medicine and is a subsidiary of London-based Advanced Oncotherapy PLC. ADAM S.A. is developing the linear accelerator to be used in the Linac for Image Guided Hadron Therapy (LIGHT) project of Advanced Oncotherapy PLC [1]. The main advantages are:

- **Precision**: the system has an active longitudinal modulation along the axis of beam propagation rather than trough degraders.
- **Compact**: the linear accelerator has compact dimensions compared to a cyclotron or synchrotron, therefore reducing size and costs of production and installation.
- **Modularity**: LIGHT is conceived as an assembly of modular units thereby facilitating installation and possible displacement to a different site.
- **High frequency**: the very short pulses (a few microseconds) typically for the linear accelerator and the high repetition frequency (up to 200 Hz) are extremely useful to perform a highly conformational therapy based on a fast 3D spot scanning of the tumor.

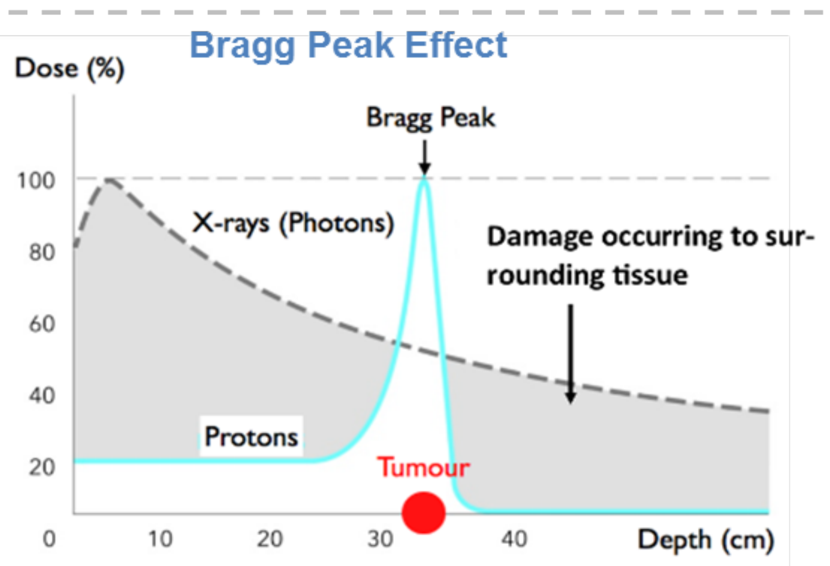

Figure 2: Energy Absorption as a function of depth.

CONTROL SYSTEM

The main requirements of the LIGHT Control System include:

- **Repetition rate**: provide beam pulses with properties (energy and dose) at a rate of 200Hz.
- **Modularity**: handling multiple suppliers and equipment evolution transparently
- **Commercial off-the Shelf** equipment to reduce time to marked and provide long term support.
- **Custom Suppliers**: Custom suppliers for the equipment in the frontend tier necessitates control system hardware.
- **Configuration**: management of configuration and calibration data.
- **Procedures**: automation of procedures for machine commissioning, operation and QA.

ARCHITECTURE

The LIGHT Control System (LCS) relies on a standard multi-tier architecture [2][3]:

- **Presentation Tier** (Tier-1) user interfaces to control and monitor services (tier-2) and equipment (tier-3).
- **Processing Tier** (Tier-2) configure and monitor the equipment (tier-3) and allows the user interfaces (tier-1) to control equipment in a uniform manner.
- **Equipment Tier** (Tier-3) abstract accelerator hardware specific interfaces into a uniform interface.
- **Frontend Tier** (Tier-4) local supplier specific control system with custom interfaces of accelerator and beamline hardware.

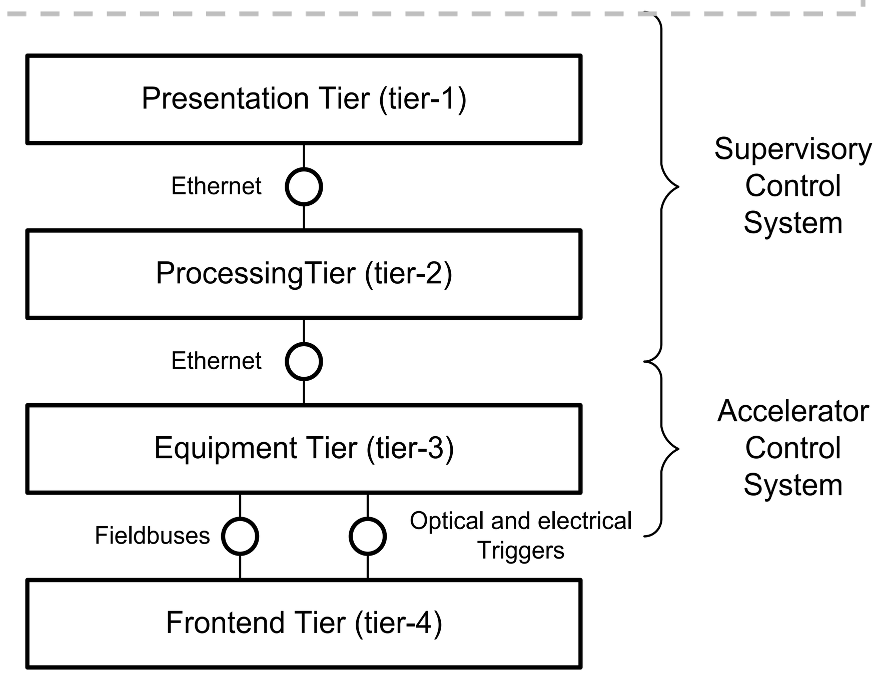

Figure 3: LIGHT Control System Architecture.

ACCELERATOR CONTROL SYSTEM

Front-End Controllers (FECs) are implemented on National Instruments PXIe systems.

- **Real-time control and monitoring** implemented on FlexRIO platform with embedded FPGAs.
- **Slow control and monitoring** implemented as a LabVIEW application on the controller, relying on the "Modular Accelerator Device Integration Environment" (MADIE), an object-oriented LabVIEW framework by Cosylab [4] to **support FEC development**, provide **unified interfaces** and is easily **extensible**.

Alternatively FECs are implemented using Siemens SIMATIC S7 for pure slow control and safety relevant systems.

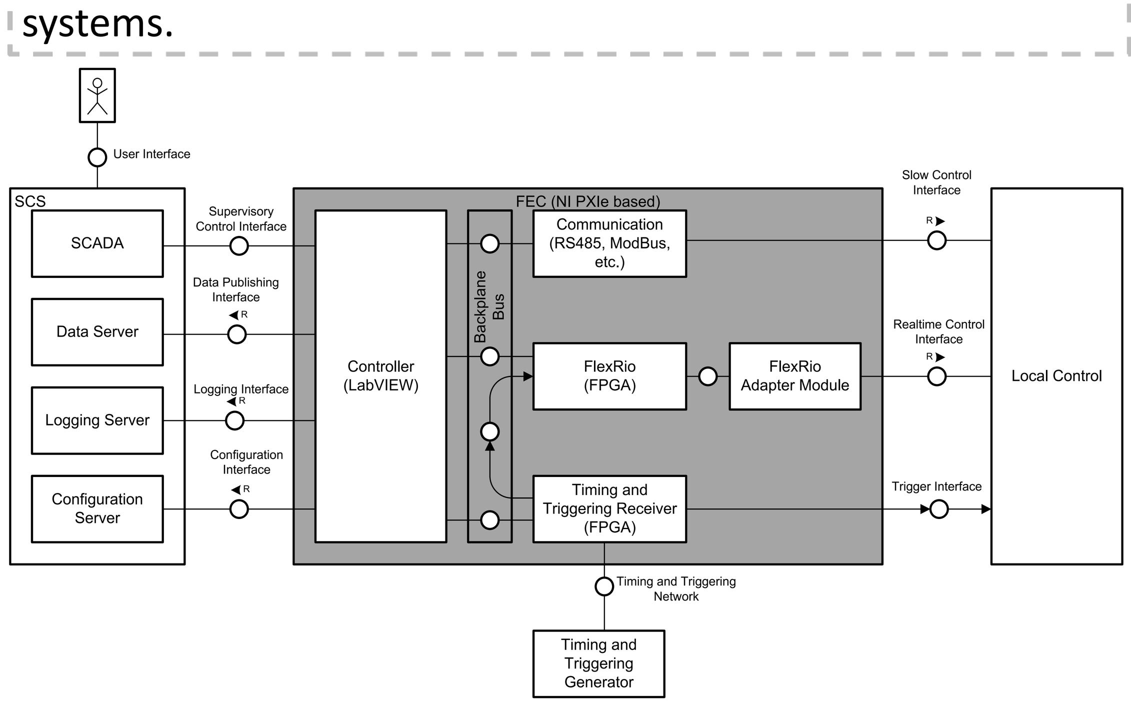

Figure 4: National Instruments Front-End Controller Layout.

TIMING AND TRIGGERING SYSTEM

Equipment is intended to be synchronized using a MicroResearch Finland based [5] timing and triggering system (TTS) which provides:

- **Sub-microsecond timestamping** of triggers and measurements on each National Instruments system.
- **Triggers** for processing and frontend tier equipment with a sub-nanosecond accuracy.
- **Distribution of Beam Requests** to all equipment to apply settings specific to beam parameters.

SUPERVISORY CONTROL SYSTEM

The main services include

- **WinCC OA** as a SCADA system including user interfaces,
- **Data Server** acting as a publisher subscriber and
- **Element Database** tracking the evolution of the accelerator equipment types, instances and settings.

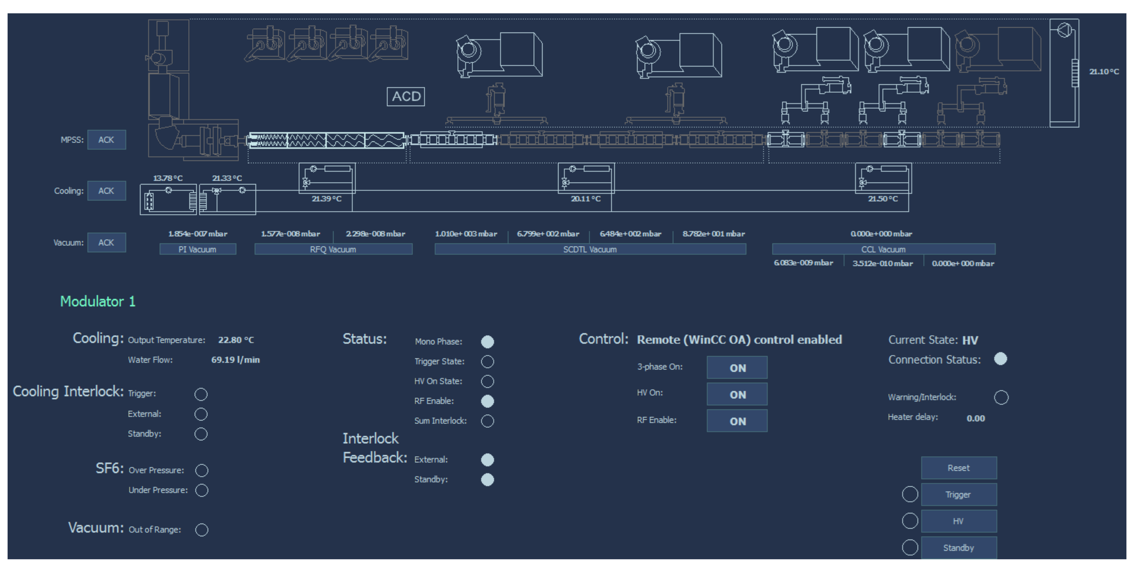

Figure 5: User interface example for the LIGHT accelerator.

INTERLOCK SYSTEMS

The Interlock Systems reduce the risk of harm to the personnel and the machine caused by erroneous situations or conflicting commands [6]. The main requirements include:

- **Mode independency** is required for the interlock systems to react the same way in all accelerator modes.
- **Uniform interlock interfaces** for the compatibility of all devices to the interlock system.
- **Failsafe interface design** assures the safe state of the connected equipment upon a disconnected wire or a wire break.
- **Manual acknowledgement** of the interlocks by an operator is required to reset the interlocks upon a resolved interlock condition.

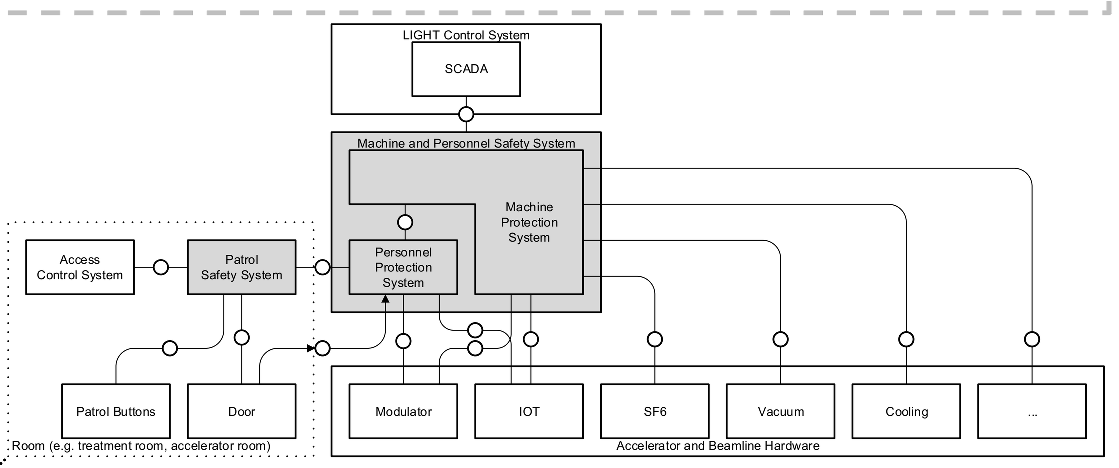

Figure 6: Example of the general layout and connections of the LIGHT Interlock Systems (grey).

PATROL SAFETY SYSTEM

The Patrol Safety System (PSS) is implemented on Siemens SIMTATIC S7 PLCs and

- **assist the patrol** of a room, consisting of opening and closing a door, inspecting of the area and pressing patrol buttons in the correct order and within a fixed time.
- **indicate room accessibility** to the machine and personnel safety system (MPSS).

If the door to the bunker is opened the MPSS immediately trips an interlock to bring all systems into a safe state to reduce the risk of harm to personnel.

MACHINE AND PERSONNEL SAFETY SYSTEM

The Machine and Personnel Safety System (MPSS) is implemented on Siemens SIMATIC S7 with an anticipated maximum reaction time of approximately 500 milliseconds. It consists of two parts:

- **Personnel Protection System** (PPS) is responsible to **minimize the risk** of unintended exposure **to ionizing radiation for personnel** when entering the accelerator and treatment rooms (fail-safe part of PLC).
- **Machine Protection System** (MPS) is responsible to **reduce the risk to** the accelerator **equipment** of harm caused by erroneous situations (non fail-safe part of PLC).

The MPSS must be **orthogonal** to the accelerator control systems and it must be **independent of** the accelerator **modes and states**.

CONCLUSION

Developing a particle accelerator for medical purposes is a challenging task for a number of reasons. Other than being a very complex device, it must also surpass the competing products on an extremely competitive market.

This article presented the overall architecture for the LIGHT control and interlock systems. The multi-tier architecture as deployed in state-of-the-art medical accelerators is used as a basis and further extended to deal with challenging requirements such as short time to market and a beam pulse repetition rate of 200Hz.

Using National Instruments and Siemens solutions at its core and the presented architecture will allow us to minimize the time-to-market and offer state-of-the-art proton therapy system with a stable long-term support.

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