Particle accelerator Control System

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Particle accelerators are an important tool for new discoveries and understanding in different principles of all branches of science and engineering. As the science is progressing, new types of techniques are discovered and journey is still going on for new innovative techniques for acceleration, mainly in achieving accelerators for high energies, high currents and so on and uses of these machines in industrial application and nuclear energy generation and waste incineration.

As accelerators increase in size and complexity, demands upon their control systems increase correspondingly. Machine complexity is reflected in complexity of control system hardware and software. Same time imposing easy access and operation of the machine with higher degree of reliability and reconfigurability. Model-based procedures and fast feedback based upon even faster beam instrumentation are often required. Managing machine protection systems with hundreds or thousands of inputs is another significant challenge. Increased use of commodity hardware and software introduces new issues of security and control.

1. Introduction

Control system is a tool to sense the status and to achieve the desired beam from the machine. It also helps in system commissioning during Machine installation and off-line analysis and fault diagnostics operation. Three major points For many years, the controls community has to take serious note while developing are : the ever increasing scale and complexity of accelerators themselves and requirements of reconfigurability for the accelerators future enhancement; their ever more demanding reliability requirements and the fast pace of technology in electronics hardware and software. These factors enforce a careful and innovative architecture for accelerator control system so that it can be used throughout the complete life cycle of accelerator development and utilization.

2. Architecture of Control System

The Basic architecture of the control system is the most important entity for any control system. The control system should be suitable for the plant not the reverse, control system's structure should reflect the plant architecture. It is a special for accelerators because of the machine it self. It requires a lot of R&D and technological development for the accelerators which have to be utilize in R& D, which needs special features from the control systems against well established process control and instrumentation from other industrial control systems.

Starting from monolithic (Single layer) architecture the control system has matured to multilayer architecture which is also known as standard model of control system. Standard model can be further classified as centralized and distributed architecture. Monolithic architecture can fit itself only in centralized architecture of control system.

2.1. Monolithic Architecture

A **monolithic architecture** is where processing, data and the user interface all reside on the same system as a part of single software program. There are a lot of appeals for a single and central system which can be listed as given below:

- A single and centralized data store .
- Only one point access to the control system, eliminating any specialized access control .
- No possibility of data duplication .
- Single technology stack so it is easy for developers to maintain
- Inherently fast and easily achievable time response.
- Lowered support base as there are fewer systems to support .
- System integration is easier as it is one system with a few external links.
- Management reporting is easier across systems as there is a single data store to pull

data form .
- A single architecture and single developer framework and tool set.
- Central collaboration and user interfaces
- Easier for users to learn the system
- Reliability can be achieved just by putting a duplicate system with simple logic .

Seeing these benefits it looks quite attractive but the pitfalls are more serious that the advantages provided by the system. Which can explained as following:
- monolithic system are unsuitable to manage the complexity in the system as any mistake done to handle will put the whole system down it is always easier to handle complexity at small level.
- As the operator interface is also an integrated part of the system , it is directly exposed to the operator and any mistake will jam the whole system.
- unsuitable for incremental development during machine commissioning and installation phase as well as up gradation of either machine or control system itself.
- Difficult to add new features to the system .

The existing control system (pelcon) of BARC - TIFR pelletron control system is an example of monolithic centralized control system which is in operation from last two decade. CAMAC crates which are interfaced to the machine are interconnected via Serial Highway Bus from master CAMAC crate in control room. Master Crate is connected with the control PC via System interconnect Bus (SIB). The PC is running a pelican control software in DOS. Which is responsible for execution of CAMAC cycle as well as User interaction via Graphical user interface. The master crate serves the information transfer between Slave Crates connected to the field devices and also provides the interaction between operator interface hardwares like analog panel meters , rotating Knobs for value control and buttons.

Though the system is successfully operating from last two decades and Superconducting LINAC Booster has been added to the system. The control system of Pelletron and LINAC can not be integrated because of the monolithic architecture of the Pelletron Control system. Also many new devices which have been connected to pelletron because of upgrade or replacement are not possible to be interfaced to the control system and are handled in standalone mode.

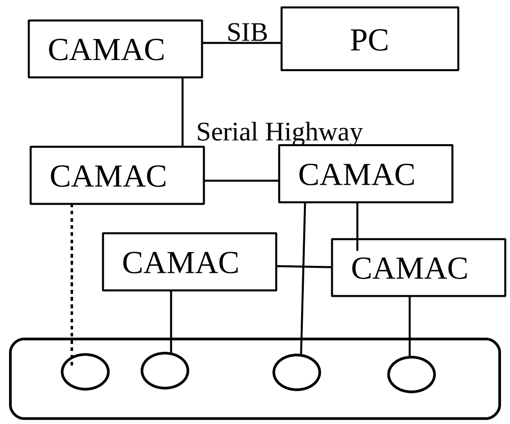

Fig.1 BARC-TIFR Pelletron Control System

2.2.Multilayer Architecture

Multilayer Architecture provides a more hierarchical architecture of control system. In a standard way control system can be partitioned in three layers presentation layer (operator interface layer), application layer (Server Layer) and resource layer (equipment layer).

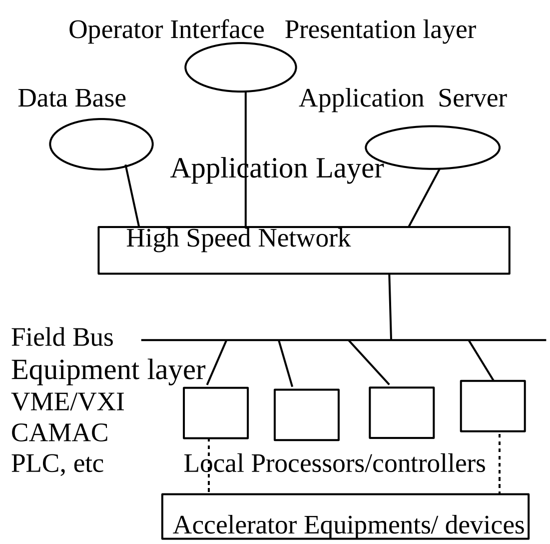

Fig.2 Multilayer Control System

Equipment layer is the lowest level of the control system which is directly interconnected to the accelerator equipments. This layer consists the bins which housed electronics modules which does the conversion between analog and digital domain. Various options are available and selection depends on individual requirements and preferences. Major systems are CAMAC, VME, VXI, CPCI or smart instruments consisting electronics interface units and digital units as part of the instrument itself.

Application layer provides different services to the other layers of control system. Major one can be remote booting and configuration of Equipment layer devices, Handling the different operations between different Equipment layer units like sequencing the operations. Application layer is also responsible for alarm monitoring and centralized interlock monitoring and data-logging. It provides different services to operator interface unit.

Operator interface unit is the layer which connects the accelerator with the human and provides interaction with the machine. It consists of many displays (graphical screens , Scopes etc) and knobs(virtual panels and hardware knobs) for monitoring and control of the accelerator.

Field Bus is the communication link between Equipment layer nodes and connects sensors, actuators or complex front-
end input/output devices to the local device servers.

Examples are profibus, RS 485 , RS 422, Ethernet , GPIB etc.

High speed network provide communication architecture manly between application layer and presentation layer. Different choices are available from Ethernet, FDDI, Token ring, WLAN .

Communication link and communication protocol is the basis of multilayer system. Depending on the interaction between the different layers of the system it can be categorized in Centralized system and distributed System. Physically hardware may be distributed which can be understood from fig 1 and Fig 4, but it is known as a centralized system.

2.2.1 Centralized Architecture

A central processor unit coordinates all communications between the consoles and the lower level distributed processing power, and continuously updates a central memory which contains the whole machine status. This memory constitutes the machine database.

Centralized systems are very simple and easy to realize the different constraints and access control of the system. Reliability can be achieved by putting a standby system.

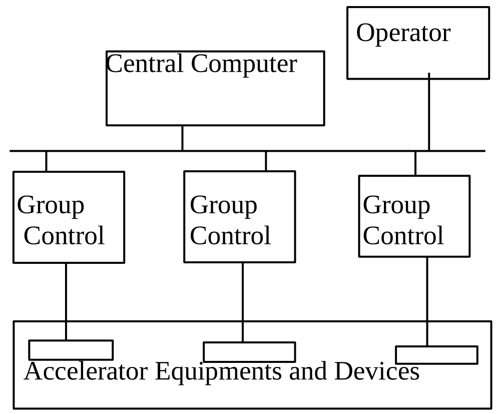

Fig.4 Centralized Control System Architecture

In Fig 4 dotted line shows the communication between different units. Here all communications are through central computer.
The control system of FOTIA at BARC i s a centralized system. It is multi-crate system .Two CAMAC crates are connected over Ethernet. Each crate controller is having an embedded PC and provides connection mode TCP port for crate access. A Multilayer system design has been followed which can be categorized in three layers (Fig1)

Front End Equipment Interface Unit (Equipment Layer)(FEEIU)

CAMAC crates are the major constituent of this layer. Despite its limitations CAMAC is widely accepted instrumentation standard for accelerator control and data acquisition systems. In house developed Ethernet Crate Controllers are having embedded processor which interacts with the CAMAC system and provides interface to user (Device Control layer) over 100 mbps Ethernet and providing interaction over connection mode TCP/IP socket.

Device Control Unit (Application Layer)

This unit consists of a PC running on Linux. This unit interacts with the front end instrumentation unit using suitable communication interfaces and protocol. It also provides services to Operator interface unit to interact with the system. This unit is responsible for the safe and reliable operation of Machine Fault tolerance and redundancy is an important requirement for this unit. The system stores all field values in a fixed memory block which makes is possible to start from the same point after a software crash. Because of this feature system can be restarted with new configuration without disturbing current setup of the machine. Redundant System has been provided to keep the system running in case of PC hardware failure.

Operator Interface Unit (Presentation Layer)

This layer includes Operator interface soft panel running on PC and other hardware panel meters and scopes for control & monitoring of accelerator sub systems. Computer Soft panel GUI (Graphics User Interface) is the most important component of this unit. The unit has to be operated by operators hence it should be easy and descriptive. The unit provides Control of each hardware units in accelerator and graphical displays of the hardware status.

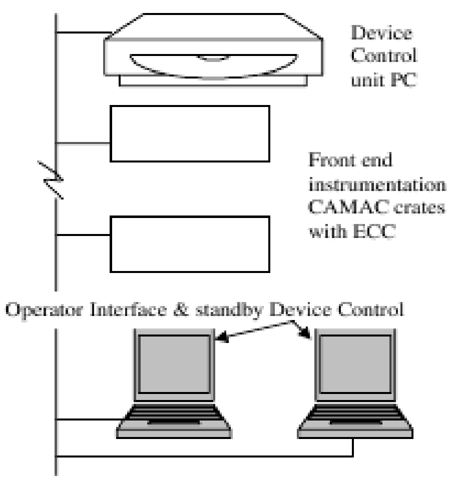

Fig.3 FOTIA Control System Architecture

2.2.2 Distributed Architecture

In a generalized distributed system the aim is to provide the user with a system where any required function/computation can be carried out wherever spare capacity exists. The user has no interest in knowing where the computation is done as long as result is provided on his end. A distributed control system is a little different from the generalized distributed system as the hardware to be controlled is connected to specific computers so the part of the program must be executed at specific location (computer). Usually the field signals will be connected to the nearest node to minimize the cabling efforts. Distributed control System are more suitable to the real system as the nodes reflects either a part or functional system of the machine.

In distributed System all group controllers can transfer information among them self without going through the Central Computer.

Distribution can be geographical, systematic, functional or mixed. In **geometric** distributed system equipment to be controlled are repeated along the accelerator. The Distributed control nodes placed at each of these points can control a portion of the system that extends all round the system. Such nodes are identical in nature. Advantage of this kind of the system is flexibility, easily expandable, and even if some of the nodes are not functioning monitoring of the parameters with functioning nodes continue.

In **systematic** distributed system system is distributed according to the the different subsystem of the accelerator like injection system, Accelerating system, Beam transport system, Vacuum system etc.

In **functional** distributed system Nodes are distributed according to their functionality. Different nodes are added to realize different functions like interlock system, alarm handling system, Timing system, Display handling system, Data logging system etc.

Real systems are always of mixed type where all three distribution or any two can be seen.

The BARC -TIFR LINAC booster is an example of distributed system. System consists Different nodes for RF control system, Beam transport system making it a systematic distributed system. RF Control System is again segmented in four distributed nodes as per the geometry of LINAC making it geometrical distributed system. There is separate system for vacuum and personal safety interlock . There are four nodes for RF control know as RF local

Control Station (RF LCS). Each RF LCS consists of a CAMAC crate and a PC and are responsible for two cryo-modules.

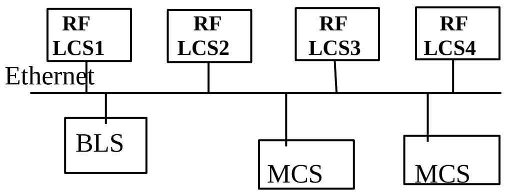

Fig.5 BARC-TIFR LINAC Control System

Beam Line Station (BLS) consists of four Ethernet to serial switches and a computer. BLS is connected to focusing and beam diagnostics system.

Master control station MCS provides the graphical panel for operator interface .

3. Software for Control System

Different type of software are used at different layer of the accelerator control system which realizes different functionality of the system with a common goal. Software is the most flexible part of the system hence demands are very dynamic, always new features are added by the software. Hence proper care must be taken from the design step to meet the future up-gradation. Fault tolerance and reliability are the most important goals to be achieved by the software. It should also provide proper mechanism for machine diagnostics which requires intelligent data logging of the system. Multiple operator interface and presentation units are always desired in accelerator control system,in that case proper care must be taken to avoid concurrent access of a single instrument or system from multiple nodes.

3.1 Operating System and Development Environment:

Multilayer system is very much suitable to meet such requirements but care should be observed to do the correct thing at right place.

Software at equipment layer should be developed with proper care and with final foot print , any change at this layer should be avoided unless and until it is the only solution. The interface between equipment layer and upper layer should be selected properly so that both the layers are immune to the changes at either layer. In fact interface between all the layers must follow the rule of immunity. Equipment layer mostly uses real time operating system as it is the layer responsible to meet the dead lines(eg Vx Works, QNX). Stable non real time system with proper care can also be used in certain cases where if the deadline is missed it does not cost the system expect the time. Though Object oriented is becoming the defato standard for the software development but most of the system calls on real time operation systems are still non object oriented. This layer highly relies on the services provided by the Operating systems, hence it should not be forced and judicious choice must be made.

Middle layer should be developed to provide services to upper layer and with a plan to add additional feature without disturbing the system and compromising on reliability. Standby systems must be used to achieve the reliable operation of the system. Operating system at this layer must be a stable system running many server services. Mostly Linux server , Solaries and MS Windows Sever edition are used at this layer. Object oriented software development is a favored choice for this layer.

Operator interface layer provides many mimic panel and display of the system in main control room . This layer should provide rich graphical interface to the system. Remote displays also provided out of control room , which requires that the system must be operable to different operating environment. Portability is an added requirement for this system, which can be achieved by Java technology, portable C++ based graphics APIs or remote logging.

Many SCADA software are also available which can be used to develop the control system software . Industrial SCADA systems are mostly avoided as they do not suit to the particle accelerator environment. EPICS SCADA[3] software is very much popular in accelerator community. It is an open SCADA system which provides the Distributed control system development based on Linux and Solaries operating system at middle layer and upper layer. At lower layer it provides good support for the Vx Works operating system. Support for other system can also be developed as it is an open system.

Example: Software for FOTIA at BARC has been developed in Linux, both equipment interface unit named as Scanner(Middle layer) and Operator interface unit are using Linux operating system. Scanner software is a multi-threaded software which interacts with CAMAC via TCP/IP client and provides connection and interaction to the operator interface unit via TCP/IP server thread. Scanner is developed in C language and uses many services provided by Linux operating system major one are shared memory access and signal handling . Scanner can be accessed by multiple Operator interface and concurrency is handled at signal level. There is only on instant possible for scanner to avoid access of CAMAC from multiple processes. Operator interface layer is developed in object oriented language and uses QT API which can compiled either on MS windows or Linux.

BARC TIFR Control system software is fully portable as it is developed on JAVA. All LCS and MCS systems are developed in JAVA. RF LCS uses TCP/IP protocol to communicate with the CAMAC crate and MCS. BLS System communicates to the different devices using 16 port RS 232 to Ethernet converter switches which acts as a protocol converter and all RS 232 devices are accessed using TCP/IP protocol. The system has multiple graphical panel developed in JAVA. Concurrency in LINAC is handled at equipment level.

3.2 Database

Data bases are used to store the parameters of the machines, the configurations of the servers and the archived on-line measurements of devices. Big Database Systems like ORACLE, MySQL, Postgresql or other standard commercial products with interfaces to different computer types are available. For on-line archiving and configuration data of front-end servers, a big database is too slow and voluminous to fit into a small front-end. A small real-time database usually adopted for time critical applications. There are three types of databases in the control system:

Static database : store configuration parameters like names, constants, calibration coefficients, attributes, alarm levels, field bus addresses, etc.

Historic database: log data over long periods of time, long-term history data are stored into a relational database and retrieved off-line for machine diagnostics.

Real-time database (Snapshot database): Stores the state of the machine in the memory and a database file for the retrieval of the system in case of failure or re-startup after schedule shutdown.

Conclusion:

Multilayer Architecture in accelerator control is extremely adaptable to provide the needs of extensible machine and will fulfill the requirements of new machines in design states. Innovative communication models and protocols will make the architecture more attractive. Fast pace of change in technology poses a big challenge for the control system as process control should use mature technologies. The wisdom is not in using cutting -edge technology but the one which really works on real machines.

Acknowledgment

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