Data Acquisition Systems - Current and future trends

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Modern day physics experiments, irrespective of the field, now seem to involve a large number of signals to be acquired and analyzed. The acquired signals may involve multiple parameters, for example in nuclear and particle physics experiments the individual signals may carry information about the energy, time, charge, mass etc of the particle or radiation that is being detected. Advances in electronic and information processing technologies have empowered the physicist to record such events and perform data analysis on the stream of data not only after the experiment is over (off-line) but also to some extent on a real time basis. The challenge for modern data acquisition systems is therefore not only in collecting, without loss (high throughput), the large number of signals, but also to efficiently extract, at high rates the information encoded in the signals. The matter is complicated by the requirements of experiments to deal with signals that occur with vastly different occurrence rates, as well the necessity to sometimes be able to co-relate asynchronous events, or events from detectors that have vastly different efficiencies. In this talk we will look at the various data acquisition systems from an engineers point of view, looking at the several seemingly contradictory requirements and how they have been dealt with till now. We will also consider some of the emerging trends in data acquisition that leverage the power of modern electronic technology that allow for high speed high efficiency data acquisition. We will consider the techniques of trigger-less data acquisition systems, time stamping individual signals, clock synchronization with global positioning systems, etc.

I. INTRODUCTION

The process of measuring real world physical property and converting the resulting samples into digital numeric values which can be later or analysed on the flow to extract information, had undergone a sea change in the recent past and is rapidly evolving. The complexity of the experimental apparatus and the need for decoding information from the acquired signals had also enforced changes in the way data acquisition systems (DAS) work. In this paper we will deal with the trends or the evolution and design considerations that had and will take place in the field of data acquisition system instrumentation, especially for accelerator based physics experiments and in particular the nuclear physics experiments. This paper will also highlight the upcoming or near future possibilites in this field.

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The complexity and the demands of the modern day experimental apparatus with varied physical property sensors, used by the experimental physicists requires DAS that are capable of

1. handling and crunching large amounts of data.
2. improvised sensor data, in terms of accuracy, resolution, bandwidth, number of channels, etc.
3. high speed inter connectivity amongst acquisition modules, for proper synchronization.
4. digital recording that can keep pace with the speed of acquisition hardware.
5. easy experiment specific tailoring of the hardware and software, with full fledged reconfigure possibility, i.e., component re-usability to the maximum possible extent.

In short an information retrieval system is what is the demand of the modern day physics experiments rather than a simple data acquisition system.

II. EVOLUTION OF DAS

From the generations of engraving down values on stone (the first known acquisition system used was by egyptian pharaohs in 2500 BC, to record water flow of Nile visibly at periodic intervals, to predict flood), then noting down on paper, to chart recorders, to data loggers with replay capability, now the DAS in the recent past or the conventional DAQ systems, consists of sensor(s), signal conditioner(s), voltage scaler(s), digital converter(s) and the read out controllers with a computer connected to it to analyse, display and digitally record the signals.

The complexity of the DAQ systems naturally tend to increase with the number of physical properties to be measured, and also with the resolution and accuracy of the measurement required.

First the problem of event identification i.e., determining the event of interest is tackled in many ways. But as the data from the sensors are random in nature, but having a certain correlation amongst them, as they are all generated from an event happening. To extract this correlation it is necessary to identify the set of signals pertaining to the event occured. This can be achieved in many ways. For example using time window detection, i.e, to detect activity in one, two, three or more sensors within an expected time window could be treated as an event of interest. This can be achieved by summing sensor activated signals and discriminating the analog summation, to detect the event of interest. The same can also achieved by having a huge high speed memory and producing a event validation with complex combinations of signals forming an event. Here a single point acquisition control and recording is used.

When the number of signals even increases from small number to medium range say around 100 or 200 signals this single point acquisition and collection the dead time increases drastically. This can be circumvent by implementing a distibuted acquisition [1], in which the signals are distributed across different read out systems with a common event identification 'tag' shared by the independant read out controllers. A futher improvement to this can be achieved by time stamping the event fragments, in a such a way it can be located apart or in other words multi strobe data acquisition systems is a possibility [6]. Such a system[2] was deployed at the Indian National Gamma Array [12] campaign at IUAC. This also had other improvements like, high precision clover module for pulse shaping[3], a high resolution eight channel analog to digital converter[5] with hit pattern capability and readout controller[4] that can handle upto 1.7 mega bytes / sec, with scalability in a ditributed fashion and hit pattern based read out facility.

When the number of signals further increases manifolds or the information required like pulse shape analysis and tracking imposes the requirement of different approaches for the data acquistion instrumentation and acquisition methodlogies. A generic method adopted by acquisition experts is to time stamp each and every signal as they are acquired and correlate them based on the time stamp. The complexity of the DAS increases based on the sensor output characteristics and information(s) required to be extracted. If tracking of the particle or to well defined position within a multi segmented detector is required then high speed flash or pipe lined analog to digital converters (ADC) with digital signals processing is the option. We will see about it in detail in the following sections.

III. SIGNAL PROCESSING AND EVENT INDENTIFICATION

Complex information retrieval from multi segmented detectors are acheived by digitally processing the signals through a high speed ADC. Normally as a thumb rule it is practically seen that the ratio between the bandwidth and that of the sampling frequency of these ADC should be at least a factor of 0.35. i.e., to measure signals with a rise time of say 35 ns one has to use an ADC whose sampling frequency is at least 100 ns. (See also what nyquist criterion**??**, means in discrete sampling and the paper by nyquist**??**). This in fact has many other parameters that play role, one of them being the jitter [10],[11] in the clock used for such an ADC. As with the high density of modules and electro magnetic interference playing a major role in the noise margin, which increases the jitter in the clock and in turn reduces the bandwidth of the ADC. This signal retrieved from the signal conditioners are directly fed to these ADC. The output of these ADC can be processed through inference engines like, moving window deconvolutors or to Kalman processing[9] engines to extract informations like energy, charge, time of incidence, rise time etc. As there are large number of signals to be read in the case of near 4 π multi segmented detectors, the way to correlate them is by means of time stamping each acquired signal to the required resolution. This can be achieved by running high precision master clock, generating a time stamp and distributing the same to all the acquisition modules, calibrating the delay by computing round trip times to achieve equi-timing at all pulse processing front ends.[13]

IV. CONNECTIVITY

The acquisition of data from such complex systems can be done through a distributed multi tier acquisition engines connected in many forms like a bus with a back plane like CAMAC, VME, VXI, PIC, PXI, PCIe, ATCA, custom made 19" pizza boxes with high speed fibre or copper links connected in a ring, fat connected (the number of links increases at every tier of the tree), fully connected (each node has an individual connection to every node) or in a star with a centralised supervisor engine. The limitations of fibre (500 MHz-Km for multi mode) are way ahead of the bottle necks of the high resolution ADCs. The consideration of replay and analysis systems, restricts the choices available.

V. TRIGGER LESS - DIGITAL RECORDING CHALLENGE

The better way of acquiring information is to record all the valid traces on a trigger less as is basis with a globally distributed time stamp, and use it for replay and analysis. But this poses a serious challenge in terms of digital recording of the data. First the volume of the data becomes so huge, that is impossible to handle it. And even if it is stored, it is not possible to analyze it as the analysis engines are relatively very slow compared to acquisition engines. The shelf life required for the data also poses another challenge with this volume. Even though solid state drives are available, they are at present not a viable solution in terms of cost. So, a trigger processing or in other words an event validation mechanism is implemented to circumvent this problem.

VI. THE NEAR FUTURE OF DAQ SYSTEMS

The recent challenge for the DAQ instrumentationists around the world is to use the low power ADCs to fit inside the cooled detectors to provide digital output signal conditioners on fibre without disturbing the the signal source with its switching noise. The recording challenge is to use compact high capacity solid state drives to record all the information possible. For example, with INGA running at 20 Kilo hits / detector can have upto 20 tera bytes a day. The near future also envisages a wire less connectivity, to these digital output signal conditioners, with a built in global positioning system based time stamping. This can help in breaking the distance barrier, with a cable less solution from the radiation prone area. With the volume of data to be handled by analysis engines, and the replay or analysis engines or generally run on sequential machines, it is relatively very slow compared to the acquisition speeds. People are exploring the possibilities of using graphics processors for analyzing the data for information retrieval as it supports massively parallel algrithms with multi dimensional memories and bit built operations. A one tera flop graphics card is easily available in the market with support libraries for programming ease. A computer farm with multiple graphics cards, with the capability to acquire and store data in a distributed fashion and at the same time analyze the data with almost no load on to the acquisition and storage engines is a possibility.

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