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presented by B.G. Gibbard

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DATA ACQUISITION FOR A LARGE NEUTRINO DETECTOR

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Abstract

A hierarchical, distributed intelligence data acquisition system which has been used for the past two years in neutrino experiments at Brookhaven National Laboratory is described. Performance characteristics and the nature of problems encountered in bringing the system to maturity are discussed and some generalizations of the experience are suggested.

Introduction

A large detector has been built and put into operation at Brookhaven National Laboratory to study neutrino electron and neutrino proton elastic scattering. Beam spills occur once every 1.4 seconds and between these spills the detector can be operated in any of 7 calibration and monitoring modes. These modes include the use of a number of pulsers and a variety of cosmic ray triggers. The system used to control the operation of the detector and to acquire and reduce the various kinds of data is a hierarchical, distributed system consisting of custom built scanners, LSI-11/03's, a PDP-11/34 and a DEC KL-10.

Detector Description

The separation of the elastic neutral current reactions, $\nu e \to \nu e$ and $\nu p \to \nu p$, from potential backgrounds requires that the detector be fine grained and as nearly completely active as possible. The detector, as shown in Fig. 1, consists of 112 standard modules, followed by a "gamma catcher" and a spectrometer. Each of the standard modules consists of an X and a Y plane of proportional drift tubes (PDT) and a layer of calorimeter (CAL) consisting of liquid scintillator filled acrylic tubes viewed from both ends by phototubes. These are followed by a block of 10 calorimeter modules with lead sheets interleaved to convert gammas which might otherwise escape from the back of the detector and to contain electron showers at the rear of the detector. A spectrometer composed of a magnet and PDT planes is located at the back of the detector and is used to measure the sign of a sample of the produced muons. Modules are 4 by 4 meters square and have a depth of 18 cm. Each electronic channel has multi-hit capability. In all, the detector has 4000 phototubes and 13000 PDTs. The system is operated in a triggerless mode. On the basis of an accelerator supplied timing signal, a 10 μsec gate is opened to cover the 2.5 μsec during which the beam spill actually occurs plus time for stopped muons to decay and for the PDT charge to drift to the wire.

Data Acquisition System

The data acquisition system used for this detector, is shown in Fig. 2. It consists of four distinct levels: 1) 12 table driven scanners; 2) 4 LSI-11 microprocessors; 3) 1 PDT-11/34 minicomputer; and 4) 1 DEC KL-10 computer. The power of such a distributed computing system depends on the ability of the system to keep all of the processors doing useful work as much of the time as possible, spending little time waiting for each other or for other system activities. For this reason the operation of the various processors of the system is asynchronous with interrupts used to announce the completion of tasks or the need of specific services. But the fact that various portions of the same beam event, and some calibration events, originate in different processors and must be assembled to make up the whole requires that there be synchronization for some activities. Synchronization at the level of a nsec required between portions of the detector under the control of different microprocessors is accomplished by a special coincidence unit called the External Start Box (ESB). This unit, enabled by appropriate bits set by the 11/34, accepts ready signals from the microprocessors involved in a particular activity and timing signal from the accelerator and the experiment's master clock. The ESB then transmits properly synchronized signals to the Timing and Gating boxes associated with each of the microprocessors.

Scanners

The scanners are built of TTL SSI and MSI logic. They are connected to an 11/03 Q-bus via a modified DRV11-B. Each scanner has 30 controlling registers which are directly accessible to the 11/03 and can move data into the 11/03 via direct memory access (DMA). The scanners control the analog to digital conversion of the data including the suppression of empty channels. They are capable of detecting a variety of fault conditions which may occur during readout and of notifying the 11/03 of those conditions. Scanners are of two types, one for PDTs and one for calorimeters. Each PDT scanner controls 16 X/Y pairs of PDT planes. This includes readout logic, logic which controls a pulser system and trigger logic for vertical cosmic rays within individual PDTs. The calorimeter scanners, each of which services 32 modules of calorimeter, contain readout logic, logic which permits triggering on vertical cosmic rays within individual modules and logic which permits triggering on the more nearly horizontal cosmic rays which pass through some number of successive modules.

The format of the data which comes from the scanner depends on the digitization process which produced it. For example the calorimeter times consist of a coarse time (based on counting a clock)and a fine time (based on measuring the charge produced by a constant current source during a fraction of a single clock period) and are represented by two separate data blocks of completely different format. The data as delivered by the scanners is not well formatted for physics directed analysis.

LSI-11/03's

The LSI-11 system consists of an 11/03 processor, 56 Kbytes of memory, a dual floppy disk unit, and a terminal line. The LSI-11's are connected via DA11-BOI links to the unibus of the PDP-11/34. These links permit DMA data transfer in either direction at rates up to 500 Kbytes/sec. The 11/03's are programmed completely in assembly language and while operated in an RT-11 environment, make very little use of system utilities. Each LSI-11 system controls the function of 2 PDT and 1 CAL scanners. These scanners can operate asynchronously each producing independent events, or can be instructed to synchronize on a single signal from the local Timing and Gating Box and thus cooperate to produce a single event.

Two programs have been developed for these microprocessors. The first is a stand alone system to be used for the installation and debugging of hardware. This program allows hardware knowledgeable users to set scanner registers in a direct way and review the resultant data in its most elemental form. The complexity involved in setting registers explicitly limits use of this program to the more simple operating modes and generally excludes modes utilizing cooperating scanners. The use of this program allows installation and low level debugging of detector hardware to be done in various quarters of the detector without conflict. This was especially important during the initial setup of the detector when many types of installation were going on in parallel.

The second 11/03 program, the one used in the normal operation of the detector, is controlled by a set of tables down loaded through the DA11-BOI link from the PDP-11/34. There are a total of 7 tables. Three tables describe the values to which the registers of each of the three scanners should be set during beam operation. Three other tables describe the values to which the registers of the three scanners should be set during non-beam calibration operations. These scanner tables also describe what register information from the scanner should be read back and included in the record of the events. Further, these tables can be used to describe the systematic variation of scanner parameters as when running through a series of pulser times or amplitudes. The remaining table describes the periodic checks which are made by the 11/03 of the voltages and currents associated with the portion of the detector under its control. This activity is accomplished using a computer controlled multichannel DVM present in each LSI-11 system. In addition to these tables, a number of flags are transmitted from the 11/34 instructing the 11/03 to begin or end various activities.

The accelerator cycle is divided by the 11/03 into beam time and non-beam time. The cycle for the 11/03 in its normal operating mode begins when it receives the PREBEAM interrupt which is derived from an accelerator supplied signal. At this time the 11/03 discontinues all non-beam calibration activity. It then loads all scanner registers in the manner described for beam activity in its tables. After the beam event is fully processed and a request has been made to transfer the data to the 11/34, the 11/03 performs a current/voltage monitoring cycle, notifying the 11/34 of any anomalies, and then returns to non-beam calibration activities.

The data acquisition function of the 11/03 consists of: 1) setting up for the simultaneous DMA from the three scanners, 2) converting the data from the raw scanner format to a format in which each hit of a detector consists of three words (an address, a count indicating time, and a count indicating charge), and 3) constructing the 11/03 data block. The 11/03 data block consists of a variable length microprocessor header with pointers to each of the individual scanner blocks followed by a scanner block for each of the one, two, or three scanners which may be in the event. The scanner block, in turn, consists of a variable length scanner header followed by the data for that scanner. The micro and scanner headers contain, in addition to an event type label and pointers, values for certain read back registers specified in the tables and an error block describing any error conditions which were encountered during the readout of that event. The read back registers describe the state of the detector at the time of data taking, including such parameters as gate width and threshold settings. In addition, they also may describe the characteristics of pulser input signals or cosmic ray trigger criteria.

PDP-11/34

The PDP-11/34 is equipped with 128 Kbytes of memory, 2 hard disk drives, 2 floppy disk drives, 2 800/1600 tape drives, 4 channels of raster type video display, and a printer/plotter. In addition to the four 11/03's which are connected via parallel links, it is connected by a high speed serial link to a DEC KL-10 computer and is connected to two CAMAC subsystems, one used to read out accelerator and beam parameters in beam running mode and the other used to read out parameters of the light pulsing calibration system. The 11/34 runs a program which is derived from the Fermilab RT version of MULTI. The data acquisition portion has been significantly modified to allow handling of the microprocessors as well as CAMAC and to allow interrupt driven communication to be conducted with the KL-10. The 11/34 serves as the control computer for the experiment. It starts and stops all activity and selects the combination of activities to be performed at any given time. On the basis of typed commands, it generates and transmits to the microprocessors appropriate tables and sets appropriate enabling bits in the External Start Box. The 11/34 also assembles complete events from the various data sources, 11/03's and CAMAC subsystems. Complete events begin with a variable length event header containing pointers to the microprocessor and/or CAMAC data blocks followed by the variable length microprocessor data blocks as described above and/or fixed length CAMAC data blocks. The 11/34 serves a dispatching function, sending any of the various event types selectively to the KL-10 and/or magnetic tape. It displays the status and statistics of the current run and the values of parameters describing the current configuration of the data acquisition system as a whole. The 11/34 performs a monitoring function on a sample of the incoming events, scanning them for scanner or micro detected error flags of which it notifies the operator and keeps a running tally. It monitors a number of parameters which describe the condition of the neutrino beam line summarizing this information in tabular and graphic form. It is also capable of displaying schematics of beam and calibration events.

DEC KL-10

The DEC KL-10 computer, operated by the BNL On-line Data Facility, is run in a multi-user time sharing mode of which one of the users is the online program supporting this data acquisition system. Analysis of events in this machine is usually done on a sample basis. Within core limitations, the online program is able to dispatch events on the basis of their event type to various analysis subroutines and to thereby simultaneously analyze all the various modes of detector operation. In practice it is rare that in addition to beam running there is more than one calibration activity occurring. There are three basic types of analysis: 1) analysis for calibration constants, 2) analysis to monitor against failures and 3) a simplified physics analysis to verify the character of the events being taken and to test the system as a whole. Associated with analysis type 2 are sets of calibration constants which are stored on the KL-10 disk and sent to the 11/34 for recording on tape at the beginning of the next new run. For most calibration and monitoring modes, only the KL-10 summaries of calibration constants and fault tables are recorded on tape although for some of the cosmic ray trigger modes, the actual raw data are also periodically recorded.

Performance

This system has been used in two experiments operating for approximately 40 weeks during the past two years. During that time approximately 5 million neutrino beam spills were recorded and approximately 10 times as many calibration and monitoring events were processed. The sizes of beam events vary greatly from event to event and depend on the type of beam used, (narrow band or wide band), (neutrino or antineutrino). A typical size is 800 16 bit words but sizes in excess of 2000 words are not uncommon. The typical data taking configuration includes taking beam events, monitoring the detector currents and voltages and interleaving one of the several pulser or cosmic ray calibration modes. Table I contains a list of the various modes available. Also listed in Table I are the linkage between various microprocessors and/or CAMAC subsystems required to assemble a complete event and the approximate event rate for each mode.

TABLE I

Detector Operating Modes

MODE	LINKAGE	TYPICAL RATE
Beam	4 11/03's + 1 CAMAC	.7/sec
V/I Monitor	1 11/03	.7/sec
Horizontal Cosmics	1 to 4 11/03's	2/sec
PDT Vertical Cosmics	1 11/03	2/sec
CAL Vertical Cosmics	1 11/03	4/sec
PDT Pulser	1 11/03	10/sec
CAL Light Pulser	1 11/03 + 1 CAMAC	.7/sec

During the early operation of this system there was a very noticeable learning curve in the effectiveness of the data acquisition system. Measures of the system performance include the frequencies of crashes, the fraction of available time lost to system problems and the amount of calibration activity which could be accomplished during a shift. Significant reductions in system related inefficiency resulted from three factors. 1) Some number of logical inconsistencies in the control and data acquisition software were found and corrected. 2) The level of reliability of the hardware was improved. 3) Operator interfacing to the experiment was facilitated by improved human engineering of system commands and by the increased experience of the operators.

A few observations are worth making about the construction of such a system which perhaps should have been known from the start but which were actually learned by experience. The purchase of commercial computer components for a distributed system should be done in a coherent manner guaranteeing that components which are supposed to be identical are, in fact, identical. The problems resulting from using nearly identical elements in symmetric positions within such a system can be significant from the point of view of both operation and maintenance. The entire question of maintenance must be addressed directly from the beginning in terms of what identical spares should be purchased and which manufacturers supply products for which adequate maintenance service is readily available. The dominant cost associated with a system of this type is that of labor; it is therefore not worthwhile to scrimp on such items as power, cooling or number of card slots all of which have the potential for aggravating maintenance problems.

A system must be designed so that it will continue to operate and at least deliver diagnostic comments even when there are many faulty subsystems within it. The ability of a system to support the debugging of its component parts should be regarded as equally important to its being able to take data efficiently when everything is working properly.

One of the most important and difficult aspects of a complex system is the way in which it interacts with its human operators. Commands should be concise. It should be necessary to tell only one computer what to do and that computer should then instruct all other computers. Any system reconfiguration required to support a particular running mode should be invoked automatically without the operator having to type additional commands. There should be a flexible macrolanguage allowing only limited options for the non-expert users and the full flexibility (complexity) of the system should be reserved for the experts when circumstances require. In the above described system, many of the operational limits which exist after two years of use derive from the difficulty of instructing the system to perform a particular combination of operations rather than from the system's difficulty in executing those operations once so instructed.

Conclusions

The advantages of this hierarchical, distributed approach to the intelligence of the data acquisition system include: 1) matching the qualities of the processors to their functions; 2) processing in parallel where appropriate; 3) allowing the partitioning of the system for relatively independent operation within a cooperating system or for totally stand alone operation. This system has proven to be very flexible and powerful and to serve its purpose well. An important aspect of the execution of such a system is careful global planning. Among the most important but less frequently considered aspects of such a plan are those relating to how the system will be set up and debugged, how the system will be maintained and how operators will interface to the system.

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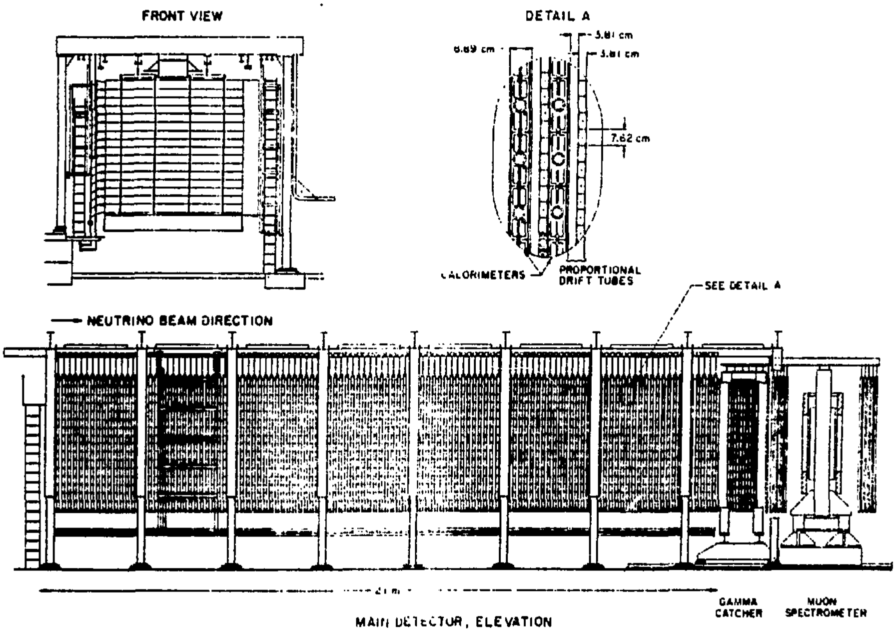

Fig. 1. Neutrino detector.

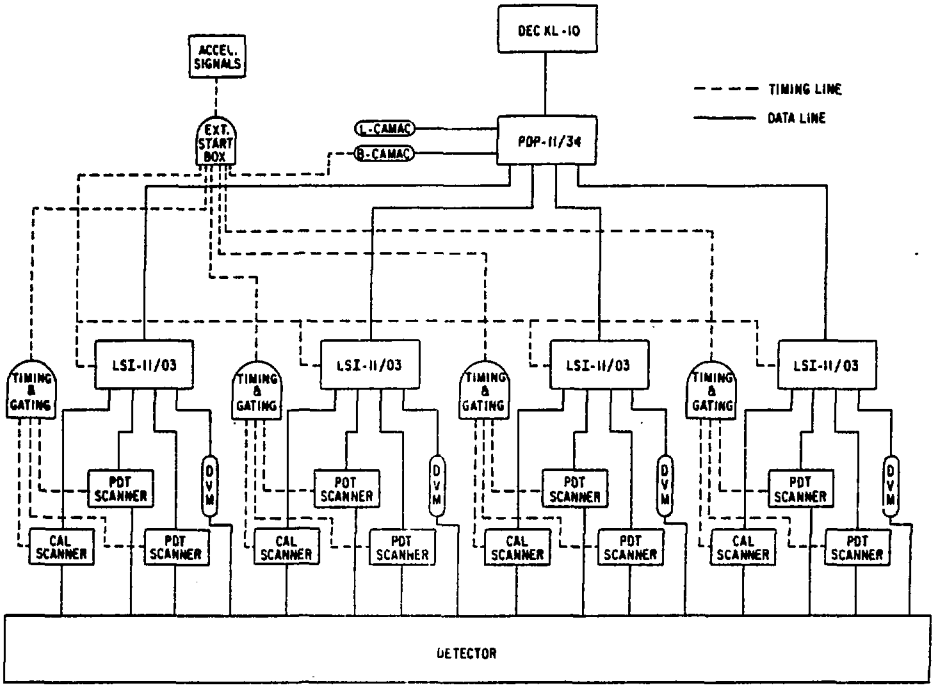

Fig. 2. Schematic of data acquisition system.