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Distributed Data Acquisition System for Pachmarhi Array of Čerenkov Telescopes

S.S.Upadhya, B.S.Acharya, P.N.Bhat, V.R.Chitnis, A.I.D'Souza, P.J.Francis, K.S.Gothe, S.R.Joshi, P.Majumdar, M.Manogaran, B.K.Nagesh, M.S. Pose, P.N. Purohit, M.A.Rahman, K.K.Rao, S.K.Rao, S.K.Sharma, B.B.Singh, A.J.Stanislaus, P.V.Sudersanan, B.L.Venkatesh Murthy and P.R.Vishwanath

Tata Institute of Fundamental Research, Homi Bhabha Road, Colaba, Mumbai 400 005, India

Abstract. Pachmarhi Array of Čerenkov Telescopes consists of 25 Telescopes distributed within an area of 8000 m^2. The array was designed to detect and process faint Čerenkov light flashes that lasts for a few nanoseconds, produced in the atmosphere by celestial VHE $\gamma-$rays or cosmic rays. In this experiment, the arrival time and amplitude of fast tiny pulses have to be measured and recorded from each of 175 photo-tubes in a shortest possible time. In view of the complexity of the system, the entire array is divided into 4 sectors. A Distributed Data Acquisition System developed for the purpose consists of independent Sector Data Acquisition Systems and a Master Data Acquisition System. The distributed data acquisition and monitoring system are built using PC's which are networked through LAN. The entire software for DDAS was developed in-house in C language under LINUX environment. Also, most of the hardware barring a few fast digitization modules were designed and fabricated in-house. The design features, implementation strategy as well as the performance of the whole system are discussed.

Key words: Distributed Data Acquisition System, Atmospheric Čerenkov technique, Distributed Čerenkov telescopes, PACT

1. Introduction

Pachmarhi Array of Čerenkov Telescopes (PACT) is a ground based atmospheric Čerenkov experiment situated at Pachmarhi, in central India. It is designed to study Very High Energy (VHE) $\gamma-$rays from celestial objects using wavefront sampling technique (Bhat, 2001; Gothe *et al.* 2000). VHE $\gamma-$rays and cosmic rays generate extensive air showers when they impinge on the atmosphere. The relativistic charged particles, like e^- and e^+ which constitues a bulk of the shower secondaries, emit Čerenkov radiation as they propagate down the atmosphere. The fast and faint Čerenkov flashes produced in the atmosphere are detected at the ground level on dark cloud-less, moon-less nights against the background of night sky light. Cosmic rays are a serious background for the detection of $\gamma-$ray signal. The experiment uses wavefront sampling technique to reject the cosmic ray background. In this technique, the density, arrival times and angles *etc.* of Čerenkov photons are sampled at many places within the Čerenkov light pool to differentiate the hadronic nature of shower from the pure electro-magnetic shower generated by primary $\gamma-$rays. The Čerenkov light pool covers a vast area, typically a circle of radius about 200 m, at the observation level. Thus the telescopes have to be spread around and the sampling of the coherent Čerenkov wavefront is to be done at several of points.

Each of the 25 Telescopes of PACT consists of 7 parabolic mirrors of 0.9 m diameter, mounted para-axially with a fast Photo-Multiplier Tube (PMT) at the focus of each mirror. We have designed a distributed data acquisition system to record data. In this paper we discuss the design considerations, custom built hardware and software in detail.

2. Design considerations for the Data acquisition system

As mentioned above PACT consists of an array of 25 Čerenkov Telescopes deployed over an area of 100 $m \times 80$ m with over 175 PMT's to sample the density of Čerenkov photons and convert them to electrical signals. The amplitude and the arrival times of these signals, which are often tiny (a few tens of mV), are to be recorded and processed in a short time. It is necessary to preserve the shape and size of the Čerenkov pulses to improve the angular as well as energy resolution and also to reject the cosmic ray background. This is accomplished by using low-loss co-axial cables to transport signals from the PMTs to the signal processing centres. In addition to recording the timing and the photometric data following an event trigger, we need to monitor a large number of direct as well as secondary counting rates periodically.

In view of the complexity of the system, time critical nature of the measurements and fast (risetime ~ 2 ns) analog signals involved, special care was taken at all levels including design, fabrication and implementation of the data acquisition system. As a result, the PACT array is divided into 4 smaller sectors with a Field Signal Processing Centre (FSPC) that processes and records information from the nearby six telescopes of each sector. One of the advantages of splitting the array into sectors is that the lengths of pulse cables could be reduced by about 60%. Analog signals from photo-tubes are brought to the respective centre through low attenuation co-axial cables, RG213U.

3. The Distributed Data Acquisition system

A block diagram of the Distributed Data Acquisition System (DDAS) developed for the purpose is shown in Figure 1. It consists of an independent Sector Data Acquisition System (SDAS) in each of the 4 FSPCs and a Master Data Acquisition System (MDAS) for the whole array. A PC functioning as System Manager in Master Signal Processing Centre (MSPC) receives the monitoring data of the various counting rates from SDASs and transfers them to an auxiliary control system of the PACT called CARAMS (Gothe *et al.*, 2001). Several other PCs connected to the network carry out online/off-line analysis of the recorded data. Most of the hardware in DDAS except for a few fast digitization modules are designed and fabricated in-house. The entire real time software for DDAS is developed in C language in LINUX environment.

Pulses from individual PMT's are processed at the respective FSPC which generates a trigger for initiating the data acquisition process. For each trigger the following informations regarding pulse height or photon density using Analog to Digital Converters (ADCs), relative time of arrival of pulses using Time to Digital Converters (TDCs), absolute time of arrival of the event (accurate to microseconds using Real Time Clock), various counting rates reflecting the sensitivity of telescopes and Latch information showing the telescopes that have participated during an event, *etc.* are recorded by FSPC. Informations relevant to entire array such as arrival time of shower front at individual telescopes, absolute arrival time of the event *etc.* are recorded by the MSPC for every trigger in every sector.

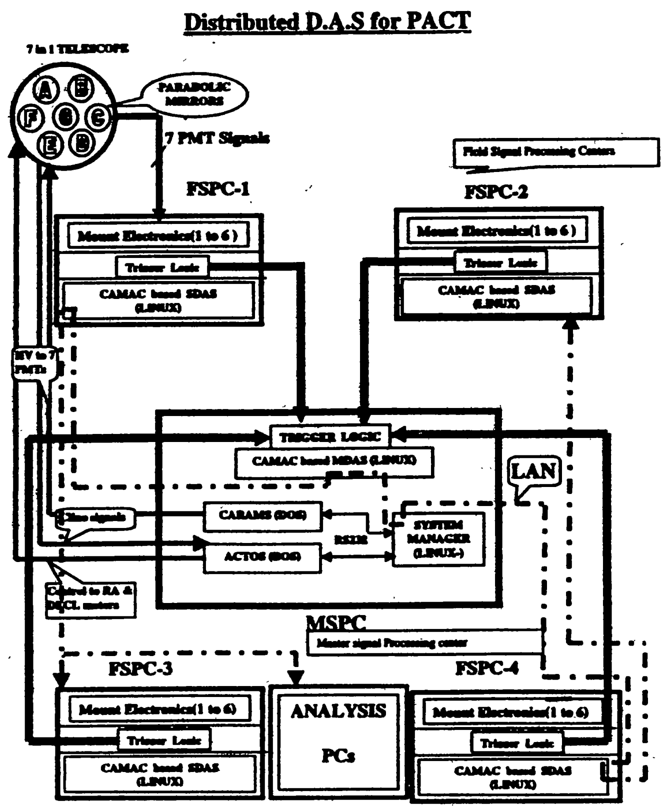

Figure 1. Block diagram of Distributed Data Acquisition System

3.1 Sector Data Acquisition System (SDAS)

SDAS is designed to process the pulses from the photo-tubes, generate a trigger and record the required information from a sector locally. The analog signals from each of the 7 PMTs of a telescope are added in phase to generate a sum pulse called the 'royal sum'. A trigger is generated by demanding any four of the six royal sums. An event so generated interrupts the PC and data recording commenses. The hardware components of the CAMAC based Data Acquisition System mainly consists of Latch, Real Time Clock (RTC), Event scalers, TDCs, ADCs and monitoring scaler modules. The TDC and ADC data from the six peripheral PMT's of the telescope, the event arrival time correct to a μs, and some house-keeping data are also recorded. The counting rates from each PMT as well as royal sums are periodically recorded during inter-event intervals.

3.2 Master Data Acquisition System (MDAS)

MDAS records data relevant to the entire array. Any of the sector triggers in FSPCs form an event trigger in MSPC which initiates real time recording of data. The data recorded primarily consists of TDC information of all the participating telescopes in the whole array and the event arrival time in addition to some house-keeping information. Using Data recorded by MDAS, data from stations can be collated off-line.

4. Hardware

The Data Acquisition system has following features: (a) modular in design concept, (b) fast CAMAC controller with data throughput rate of 1Mbytes/sec, (c) low cost modules with built-in flexibility.

Some of the modules that are designed and fabricated in-house are listed below and explained briefly.

4.1 Digital Delay Generator:

In this experiment, the relative arrival time of shower front at each mirror has to be recorded accurately to know the direction of arrival of the shower. This is achieved by measuring the time delays of individual PMT pulses with respect to the common trigger pulse. As it takes some time to generate the trigger pulse, based on individual PMT pulses, some of the PMT pulses arrive earlier to the trigger pulse and some arrive much later. Thus the PMT signals have to to be suitably delayed and fed to TDC's as individual stops. The typical delay needed is about 250 ns, dictated by the size of the array. The conventional technique to delay a pulse is by using co-axial cables. This method is not suitable especially when large delays are involved because the signal gets distroted due to propagation in lengthy cables. So, we have designed an ECL based variable digital delay generator. The is a NIM module with 8 channels. The delay for each channel could be independently set using a front panel potentiometer with in the range 50 - 600 ns. The set delay is stable within $\pm$ 0.2 ns. It supports NIM/ECL input, NIM/ECL ouput.

A low cost, TTL based version of the above module is also designed. The range for setting the delay is 120 - 1000 ns while the delay stability is slightly poorer ($\pm$ 0.5 ns).

4.2 CAMAC controller:

Each Data Acquisition System requires one set of 'controller' and an IO card. The controller is a 16 bit module with throughput rate of 1 MBytes/sec in 'auto-repeat' mode. The 'auto-repeat' mode is used whenever same CAMAC commands are to be issued for a series of successive channels. In this mode while the data of the current channel is readout the channel address is automatically incremented and the READ command is issued. This feature and the use of 16-bit word made it possible to achieve the high throughput rate.

4.3 Real Time Clock:

This is a CAMAC based module which records the event time precisely from 0.2 μs to 4 digits of day with time resolution of 200 ns. RTCs of all stations are synchronized to a GPS clock by clearing the micro and milli second counters at every second. It has several other features like local/remote loading capability, SYNC failure detection, internal/external basic clock selection, user selectable calibration triggers and optional visual display.

5. Software

The function of DDAS is to divide the main tasks (Program modules) into following sub-tasks:

a. Time Synchronization of RTCs: All RTCs are driven by a common 1MHz clock signal generated by an oven controlled quartz crystal oscillator. Time in each RTC is loaded by remote login from the central control room. 1 Hz *sync* pulse from the Global Position Satellite (GPS) Clock is enabled using a hardware switch in the Master Signal Processing Centre at a preloaded GPS time. The GPS *sync* pulse also clears the microsecond and millisecond counters in each RTC. Thus all RTCs are synchronized with GPS time.

b. Adjusting rates of all Photo-tubes: This is done by CARAMS linked through serial port to System Manager which supplies the count rates of PMTs received from SDAS's via LAN.

c. Data recording and Monitoring: Real time Data Acquisition programs are run in each of the SDASs and MDAS by the System Manager by logging into respective host PCs. Software has two main interrupt services namely 'event routine' and 'monitoring routine' invoked in real time by event and monitor triggers respectively. Event routine records 118 words of Čerenkov shower information where as monitor routine records PMT rates and telescope trigger rates into respective files. All the event and monitoring data are recorded onto local hard disks.

d. On-line analysis : On-line analysis of recorded data is carried out for a quick check on the reliability of data using networked PCs.

The basic program modules developed for the above tasks are: Device Driver Module (DDM), Device Driver Control Module (DDCM), Data DiSPlay module (DDSP) and Data Server Module (DSM).

A loadable character device driver, DDM, is developed as a part of Linux Kernel. It supports the functions like initialization, interrupt service routine, ioctl (input, output control) functions apart from Open, Close, Read and Write. Open & Close functions allow single access to hardware. Interrupt Service Routine adopts DOUBLE BUFFER scheme for data storage of size 100 events each. Checksum word is used at the end of each event data for reliability of recorded data. Ioctl module is an interface between DDM and DDCM. The DDM module receives the command from DDCM and acts accordingly on the hardware (CAMAC Controller). The DDCM is a user program which offers a simple user friendly menu by which user can control the DDM functions as well as data recording to a file. DDSP is an online data display module providing the observer the facility to check the health of the data and take necessary action. This Client program also transfers monitored PMT rates to Server program (DSM) running in the system manager using SOCKET interface library routines. The DSM is basically developed as part of CARAMS and it supplies the PMT rates through RS232 serial port.

6. Performance

The Distributed Data Acquisition System developed for PACT is functioning satisfactorily for almost two years. Data from established standard γ−ray sources have been obtained and analyzed.

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