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# Auxiliary control systems for Pachmarhi Array of Čerenkov Telescopes

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**Abstract.** Pachmarhi Array of Čerenkov Telescopes (PACT) consists of 25 Telescopes deployed over an area of 100 $m$ × 80 $m$. The experiment is based on atmospheric Čerenkov technique to detect Very High Energy celestial $\gamma-$rays using wavefront sampling method. Each telescope consists of 7 large area parabolic mirrors mounted para-axially on an equatorial mount and a fast photo-multiplier tube at the focus of each mirror. For efficient operation of the experiment 3 automated control systems were developed and installed, *viz.* Automated Computerized Telescope Orientation System (ACTOS) to control the pointing and tracking of individual telescopes, Automatic Photo-multiplier Exposure System (APES) to facilitate the exposure of photo-tubes only during observations, and Computerized Automated Rate Adjustment and Monitoring System (CARAMS) to ensure uniform gains for all the phototube - mirror systems. The design features and performance of each of these systems are discussed.

*Key words:* Telescope orientation, Control systems, PACT, Atmospheric Čerenkov technique, Ground based $\gamma-$ray astronomy

## 1. Introduction

The ground based $\gamma-$ray astronomy relies on Atmospheric Čerenkov Technique where one detects and processes fast and faint Čerenkov light flashes produced by celestial Very High Energy (VHE) $\gamma-$rays or cosmic rays. Detection of $\gamma-$ray signal against the copious cosmic ray background is a formidable task which could be accomplished by the wavefront sampling technique (Bhat, 2001). In this technique, the density, arrival times and angles etc. of Čerenkov photons are sampled within the Čerenkov light pool which extends to large distances of about 150 $m$ in all directions. Thus the telescopes have to be spread around to sample the wavefront.

The Pachmarhi Array of Čerenkov Telescopes (PACT) is one of the unique experiments at Pachmarhi (M.P., India) based on the above method for the astronomy of VHE $\gamma-$rays. The experiment consists of 25 Čerenkov Telescopes deployed within an area of 100 $m \times 80$ $m$ in the form of a rectangular $5 \times 5$ matrix. Each telescope consists of 7 parabolic mirrors mounted on an equatorial drive and is independently steerable in both E-W and N-S direction with $\pm 45°$ from zenith. A schematic of a telescope mount is shown in Figure 1. The Čerenkov photons in a shower are detected using a fast photo-multiplier tube (PMT) at the focus of each mirror during dark moon-less cloud-less nights. In all there are 175 photo-multiplier tubes.

The essential activities before each observation cycle include orienting and aligning the telescopes in the direction of a celestial source of interest, exposing the PMTs to the night sky and applying the proper voltages to them. The high voltage for a PMT depends on several parameters like the reflectivity of the mirror, gain of the individual PMT, clarity of the atmosphere and brightness of the very region of sky under observation. Also during the observation one has to monitor the tracking of all telescopes and apply corrections if necessary, monitor the rates and high voltages of all PMT's.

Manual operation of all these activities would be laborious and time consuming, especially since there are large number of telescopes and photo-tubes spread over a vast area and the observation time per source is limited. This results in the loss of precious observation time. Also in case of manual tracking of the telescopes, failure if any, will go unnoticed resulting in erroneous data. Thus precise and automated control systems are needed to carry out these tasks. We have developed rather inexpensive control systems for these purposes, *viz.* Automated Computerized Telescope Orientation System (ACTOS), Automated Photo-multiplier Exposure System (APES) and Computerized Automated Rate Adjustment and Monitoring System (CARAMS).

In this paper we describe the design features and performances of these systems in detail.

## 2. Automated Computerized Telescope Orientation System (ACTOS)

### 2.1 ACTOS Hardware

ACTOS is a PC-based system for remotely controlling the movement of telescopes. The basic block diagram of the system is shown in Figure 2. The hardware designed in-house consists of a semi-intelligent closed loop feedback system with built-in safety features. A gravity based low cost angle sensor, called Clinometer, is used as an absolute angle encoder to infer the telescope angle. Clinometer when rotated about its sensitive axis produces a signed dc voltage proportional to the angular displacement with respect to the local vertical, about $\pm 60mV$ per degree. Two clinometers are mounted on each telescope to get the angles in E-W and N-S directions. Clinometer outputs are fed to a low-pass filter and an integrating type ADC which is read by the host PC. The clinometers are

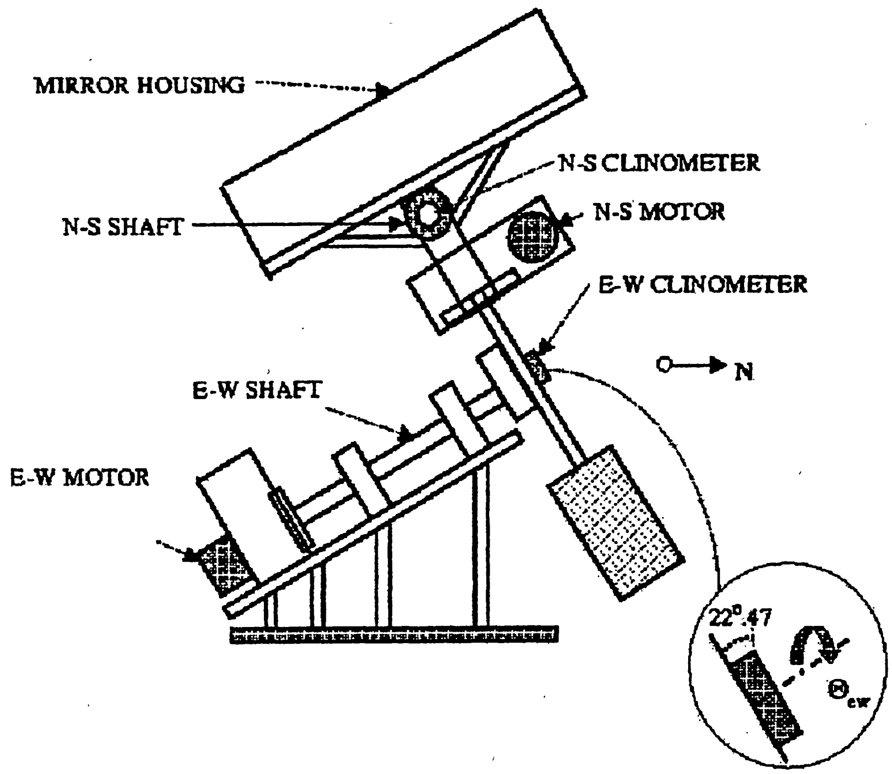


**Figure 1.** Schematic diagram of telescope system

calibrated against the telescope angles using a simple but reliable method wherein one aligns the telescopes manually to bright stars and measures the clinometer voltages. The typical responses of clinometers during the field calibration are shown in Figures 3(a) and (b). The Motor Controller, an interface between the host-PC and the stepper motor carries out the actual task of controlling the stepper motor movement according to the motion parameters like number of correction counts, motor slew speed, direction etc. which are received from the PC under program control. Variable slew speeds are used to decelerate the speeding telescope in steps. At present 3 different speeds are used, *viz.*, fast (70 Hz), slow (30 Hz) and tracking (7.561 Hz). In the process of sequential scanning of all the telescopes, the control program doesn't have to wait for any corrective action to get executed as that task is handled completely by the motor controllers and thus the whole control operation takes place in virtually parallel mode.

## 2.2 ACTOS Software

The software code for ACTOS is developed in-house in Turbo C language under MS-DOS environment. It is designed to perform two basic functions namely, aligning all the telescopes to a given celestial source and set them in source tracking mode (Alignment

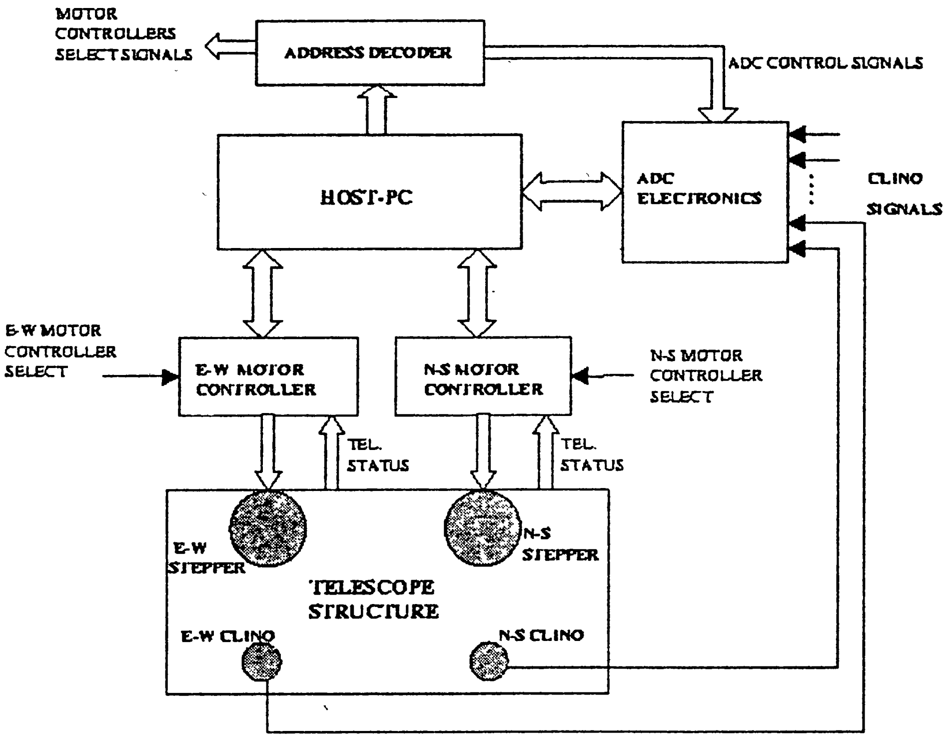


**Figure 2.** Block diagram of ACTOS

mode) and thereafter monitor continuously the position of each telescope taking corrective action if necessary (monitoring mode). The outline of the alignment algorithm is as follows:

```
Repeat
    For (telescope_no=0 to telescope_no=max_telescope_no)
        If (NOT Unused telescope)
            Ra_correct(telescope_no)
            Scan_slew_status()
            Dec_correct(telescope_no)
            Scan_slew_status()
        End_if
    End_for
Until mode=aligned for all the telescopes
```

In the above algorithm, ra_correct and dec_correct are the functions that perform the angle corrections in E-W and N-S directions respectively and the scan_slew_status() checks the status of the correction processes of all the telescopes and alters slew speed of the telescopes if necessary.

While performing these essential tasks outlined above, ACTOS software provides a graphical user interface. It facilitates the user to see the status of all the telescopes like slew speed, pointing errors, limit-switch-status etc. The user can carry out many functions online during the course of an observation by way of console interrupt facility. These functions include displaying the statistics of the movement of a given telescope (number of corrections, amount of corrections etc.), change the status (used or unused) of a telescope, change-over to a new source direction etc.

The ACTOS has been in operation since January, 1992. Recently, the software is upgraded to include several new utilities and safety features. The system can orient the telescopes to the putative source direction from an arbitrary initial position within $\sim (0^\circ.003 \pm 0^\circ.2)$. The source pointing is monitored constantly at an accuracy of $\sim 0^\circ.05$ and corrected in real time. For details on ACTOS refer to Gothe *et al.*, (2000).

## 3. Automatic Photo-multiplier Exposure System (APES)

The Automatic Photo-multiplier Exposure System (APES) is developed to protect the photo-cathode of PMTs and expose them to night sky only during observations. This is accomplished by the help of a remotely controlled moving shutter operated by a geared motor system. The shutter is opened at the start of an Observation and closed at the end. The motor (model: 49TYJ-30/500; make: Ningbo shenjiang Electromotor and Appliances) operates on 220V AC at 50Hz. The extreme positions of the shutter are defined by limit switches. Actuating of limit switch causes the motor to stop by cutting off the supply to motor and activate a remote display which indicates the current status (open or close) of the shutter. Manual switches are used for ease and simple

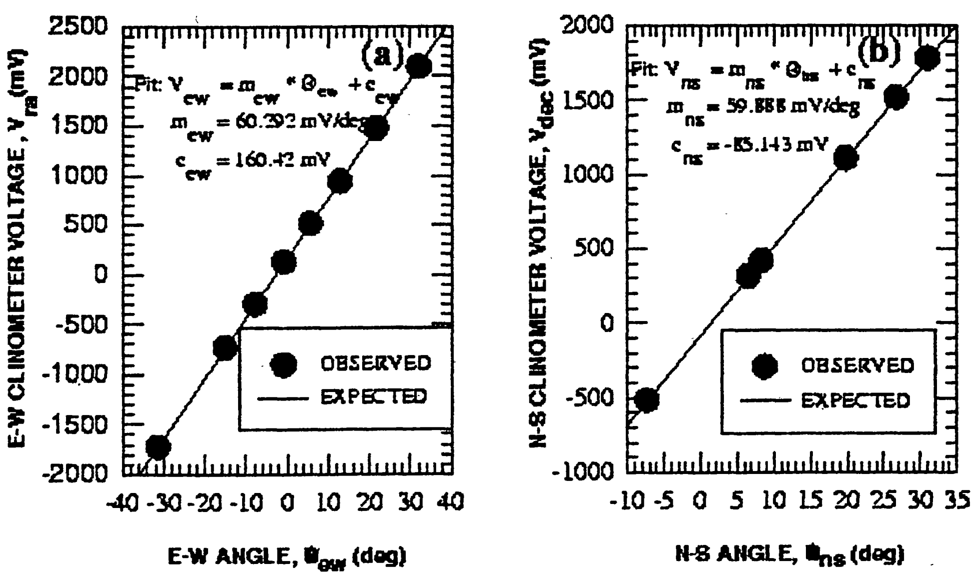


**Figure 3.** Typical response of clinometers - output voltage vs angle of rotation

operation to control every 42 shutters. This system controlled at each of the field signal processing stations by way of simple switch set-up protect the photo-cathodes during the day as well as provide an effortless and quick way to expose them during night observations. The system is implemented for 168 PMTs on 24 telescopes in the field. It takes about 1 minute to either open or close the shutters.

## 4. Computerized Automated Rate Adjustment and Monitoring System (CARAMS)

The main aim of CARAMS is to set and control the voltages of PMTs such that the gains of all PMT - mirror systems are more or less equal. This is achieved by setting the voltages on each PMT's by demanding approximately equal pulse rates due to night sky background light. The high voltage (HV) for a PMT depends on several parameters like the reflectivity of the mirror, voltage - gain characteristics of individual PMTs, clarity of the atmosphere, ambient temperature, light pollution and brightness of the very region of sky under observation. Some of these are dynamic. CARAMS is developed for adjusting individual rates/HV and monitoring them. It makes use of microprocessor-based 64 channel high voltage divider units (C.A.E.N. model SY170A) which in turn is controlled by a CAMAC based Controller Module (C.A.E.N. model CY117B). The 64 channels in a given crate (SY170A) is grouped into 4 different boards each catering to 16 PMTs. All channels in a board are fed with same input voltage. The output voltage from each channel is adjusted using a variable resistance divider network driven by a micro-motor. The HV control software developed for the purpose can set or change voltages to PMTs as well as read them back by giving proper CAMAC commands to the Controller module. PMT count rates are measured by scaler modules and are supplied to CARAMS by the system manager PC through a serial link (Upadhya, *et al.*, 2001).

As the 'Rate vs Voltage' curve for a given PMT shows day to day variations owing to the factors mentioned above it is essential to know the average behavior of each PMT-mirror combination. This is done by obtaining global fits to the 'Rate vs Voltage' curve for every PMT, by varying the voltages over a wide region in steps and reading the corresponding rates. These fits are obtained for different regions of the sky of our interest and the fit parameters are stored. In the beginning the HV control software computes the necessary voltage to get the required count rate for a PMT using the fit parameters. Later the control software uses the 'Successive Approximation Logic' for the fine tuning of HV. The system reports the faulty channels if any, with possible reasons so that the user can fix the problem easily. An option to adjust the voltages manually is also provided for. The entire software is developed in Turbo-C under MS-DOS environment.

### 4.1 Performance of CARAMS

Almost 70% of the PMTs HV adjustment take less than 5 iterations during the fine tuning process of the HV control software. The typical time taken to adjust the HVs of 168 PMTs is about 20 minutes. CARAMS is indeed fast and efficient.

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