The trigger and DAQ system of the surface detector array of the Telescope Array experiment

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***Abstract*. The surface detector (SD) array of the Telescope Array (TA) experiment consists of 507 plastic scintillation detectors, deployed on a square grid with 1.2 km spacing. The trigger and DAQ system of the TA surface detector array is the key to provide reliable SD data. To achieve efficient SD DAQ, we divided the whole area into three regions which have one communication tower with one host electronics system respectively. The host communicates via radios with each surface detector in the region.**
We developed a real-time system that monitors a variety of information in the background for SD calibration and maintenance.
The trigger and DAQ system began full operation in March, 2008. We installed a cross-boundary trigger between neighboring regions to make the shower trigger efficiency uniform in the whole region except the border of the array in November, 2008. Here we report the detail of the TA SD trigger and DAQ system.

***Keywords*: Ultra High Energy Cosmic Rays, Surface Detector, Trigger and DAQ**

I. Introduction

The Telescope Array (TA) is the hybrid detector composed of an array of surface detectors (SDs) and fluorescence detectors (FDs) to measure the energy spectrum, arrival directions, and mass composition of Ultra High Energy Cosmic Rays (UHECRs) [1]. The surface detector array consists of 507 plastic scintillation counters, deployed on a square grid with 1.2 km spacing to sample air shower particles on the ground. The array is located in the western desert of Utah, USA, and covers an area of about 700 km^2.

As the surface detector, we adopted AGASA-type plastic scintillator, which is sensitive to electromagnetic component of air showers and less sensitive to hadronic interaction models and mass composition of primary cosmic rays. We can determine energy of extensive air showers of UHECRs by surface detectors alone with the help of air-shower MC simulation independently of fluorescence detectors. The fluorescence detectors run only on clear moonless nights (10%) while the surface detectors run continuously for 24 hours (∼100%). The SD measurement provides larger statistical sample at the highest energies, and it provides reasonable accuracy to measure arrival directions of UHECRs. The trigger and DAQ system of the surface detector array is the key to provide reliable SD data.

To achieve efficient and stable SD DAQ, we divided the whole area into three sub-arrays which have one communication tower with one host electronics system respectively as shown in Fig. 1. The host communicates with each surface detector in the sub-array by using an 802.11g wireless network.

Gain and linearity of readout system are very important for SD calibration. We developed a real-time system that works in the background to monitor a variety of information. Since three DAQ sub-arrays were operated independently, there was inefficiency of shower trigger around the boundaries of neighboring sub-arrays. It was necessary to install a cross-boundary trigger to make the shower trigger efficiency uniform inside the whole region.

Here we report the detail of the trigger and DAQ system of the surface detectors. In section II, scintillation detectors and electronics are described. Section III is devoted to communication, trigger, and DAQ. In section IV, calibration and monitor are presented.

II. Scintillation detector

A surface detector consists of plastic scintillators, wavelength shifter (WLS) fibers, PMTs, electronics, wireless LAN communication system, and a solar power system. A scintillation counter is composed of two layers of plastic scintillator 1.2 cm thick with an area of 3 m^2. The WLS fibers 1 mm in diameter are installed in the grooves at 2-cm interval on the surface of the plastic scintillator. Both ends of the fibers on one layer are bundled and optically connected to a front of a PMT. The scintillation counter is contained in a 2.3m×1.7m×10cm stainless steel box.

The SD electronics consists of two channels of 12-bit

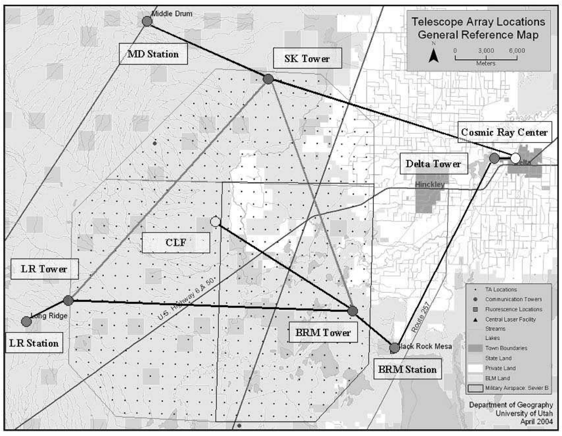

Fig. 1. The overview of the TA detector. Each dot represents one surface detector. Three communication towers (BRM, LR, and SK) are located near the edge of the surface detector array. The corresponding SD DAQ sub-arrays are called BRM, LR, and SK sub-arrays, which are the southeast, southwest, and north sub-arrays respectively.

flash ADCs (FADCs) with 50 MHz sampling, FPGA for fast signal processing, CPU for slow signal processing, CPLD for board control, one charge controller, ADCs for monitoring, and DACs for setting high voltage of PMTs through power bases. Signals from the PMTs are continuously digitized using FADCs. When signals from two PMTs of the surface detector exceed 0.3 of the single muon peak, Level-0 trigger is generated and the wave form is stored locally in a memory with a time stamp by a GPS (Motorola M12+ Timing Oncore Receiver). The relative timing between remotely separated surface detectors is maintained within 20 ns by the GPS for the good resolution of arrival direction. The planar-type antenna is used for most of the surface detectors while the parabolic antenna with higher gain is used for the detectors far or out of sight from the tower. It is impossible to distribute triggers and clocks in real time because the size of the array is large. The surface detectors are operated autonomously and synchronized to each other. More details for the surface detectors and their performance are found in [2].

III. Communication, trigger and DAQ

Each surface detector is equipped with a commercially produced wireless LAN modem board with the maximum speed of 11 Mbps using 2.4 GHz spread spectrum technology by using an 802.11g wireless network, and we use the speed of 2 Mbps. For each sub-array, one communication@tower with one host electronics system is built around the edge of the array. A colinear antenna which is indirectional in azimuth is connected to each host SD electronics. The host communicates with each surface detector in the sub-array.

The communications system between towers or between a tower and a FD station uses a standard communications architecture based on commercially available microwave equipment to provide point-to-point links. It operates in the 5.8 GHz band.

When both PMT signals of the detector exceed a trigger threshold of three muons, the trigger timing information is locally stored in a trigger list (Level-1 trigger), which is transmitted to the corresponding host SD electronics at 1 Hz by wireless LAN communication. The list contains less than 100 events for normal counters.

The host SD electronics decides the final coincidence trigger based on the trigger table with the requirement of clustered hits (at least three adjacent counters) and a time window within 8 μs (Level-2 trigger or shower trigger) to take wave forms from the surface detectors as a shower event. The trigger rate of air shower events taken at each tower is around 0.003 Hz.

When an air shower trigger is generated in a host SD electronics, a command is sent to all counters, and relevant counters storing the event with good coincidence timing (± 32 μs) respond by transmitting the wave form data to the host SD electronics.

Dead-time-less DAQ operation is aimed with the high transmission speed together with a large buffering memory at each counter. The data in a host SD electronics on the tower are transmitted and once stored in an tower PC inside a cabinet at the tower site. The data taken in the tower PC are later transmitted via tower-to-tower wireless LAN communication system to a mass storage at the Cosmic Ray Center in Delta City which is located to the east of the TA site. More detailed description of the wide area radio network for the TA experiment can be found in [3].

The trigger and DAQ system began full operation in March, 2008. There was inefficiency of Level-2 trigger around the boundaries of the neighboring DAQ sub-arrays as shown in Fig. 2. We installed a cross-boundary trigger between neighboring two or three regions to make the Level-2 trigger efficiency uniform inside the whole region except the border of the array in November, 2008. One of the three tower PCs was defined as a central PC and trigger information from two other tower PCs is transmitted to the central PC via tower-to-tower wireless LAN communication. Fig. 3 shows the map of triggered surface detectors after installing a cross-boundary trigger. We do not have inefficiency of Level-2 trigger around the boundaries of DAQ sub-arrays.

IV. SD calibration and monitor

We developed a real-time system that works in the background to monitor a variety of information for SD calibration and maintenance. We have the following real-time monitors for each detector:

- Every second,
  - the number of events with more than three muons (for Level-1 trigger rate)
  - GPS time stamps
  - maximum clock count between 1 pps
- Every minute,

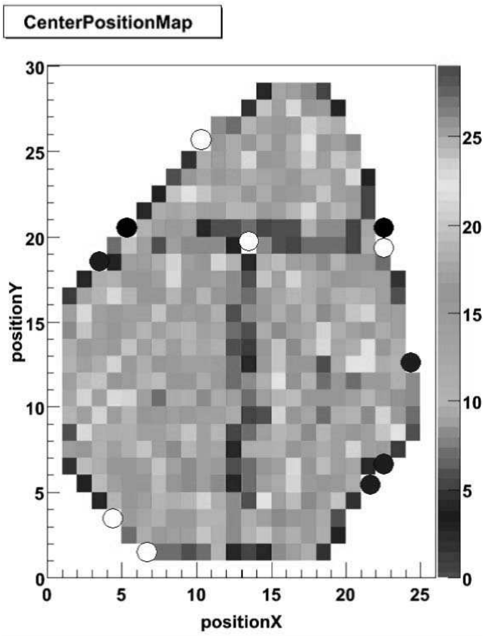

Fig. 2. A map of surface detectors that are in the middle of three neighboring triggered detectors before installing cross-boundary trigger. There was inefficiency of Level-2 trigger at around x=13 and y=20.

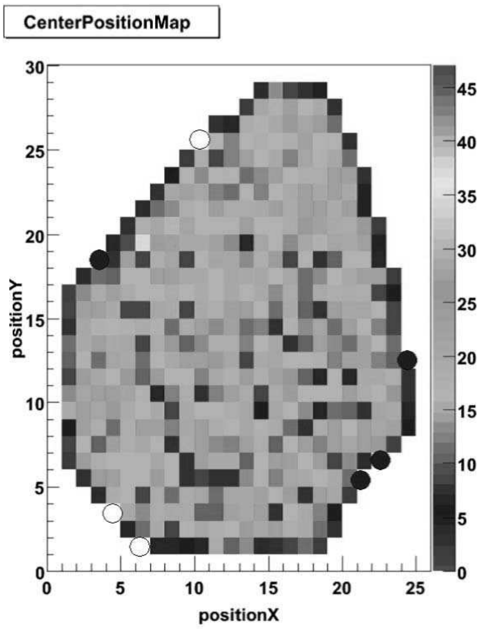

Fig. 3. A map of surface detectors that are in the middle of three neighboring triggered detectors after installing cross-boundary trigger.

  - the number of events with more than 0.3 muons (for Level-0 trigger rate)
  - battery voltage
  - charging current
  - voltage of solar panel
  - temperature at several positions and humidity inside the detector
- Every 10 minutes,
  - charge histogram (for gain calibration)

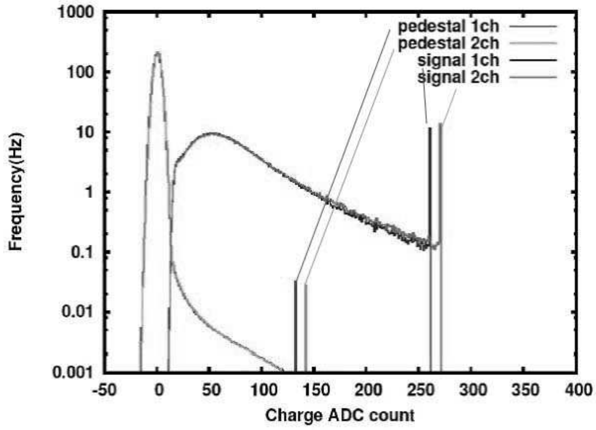

Fig. 4. Examples of pedestal histograms and charge histograms for one surface detector taken in real-time monitoring. The left histograms are pedestal distributions for the upper and lower layers. Here the peak positions are adjusted to zero. The second peaks are signals mainly of throughgoing atmospheric muons for upper and lower layers. The right most entries for all histograms show overlow.

  - charge histogram (for linearity check)
  - pedestal histogram
  - GPS condition (the number of detected satellites and the condition of GPS antenna connection)

Fig. 4 shows charge histograms and pedestal histograms. The peaks due to single muons crossing the scintillators are clearly seen. The charge histograms are used for SD calibration. Details about SD calibration can be found in [4].
Fig. 5 shows examples of several monitors from one surface detector for six days. The number of detected GPS satellites is about eight. The battery voltage changed from 12.2 to 13.4 V. The maximum charging current reached 1.5 A and discharge current was about 0.3 A during night. Level-0 trigger rate was about 750 Hz, and Level-1 trigger rate was about 20 Hz. The temperature inside the detector changed from -8 to 23^{o}C and the humidity changed from 20 to 60%.

V. Summary

The trigger and DAQ system of the TA surface detector array began full operation in March, 2008. We have a real-time system to monitor a variety of information in the background for SD calibration and maintenance of the detectors. We installed a cross-boundary trigger between neighboring DAQ sub-arrays in November, 2008 and made shower trigger efficiency uniform inside the whole array.

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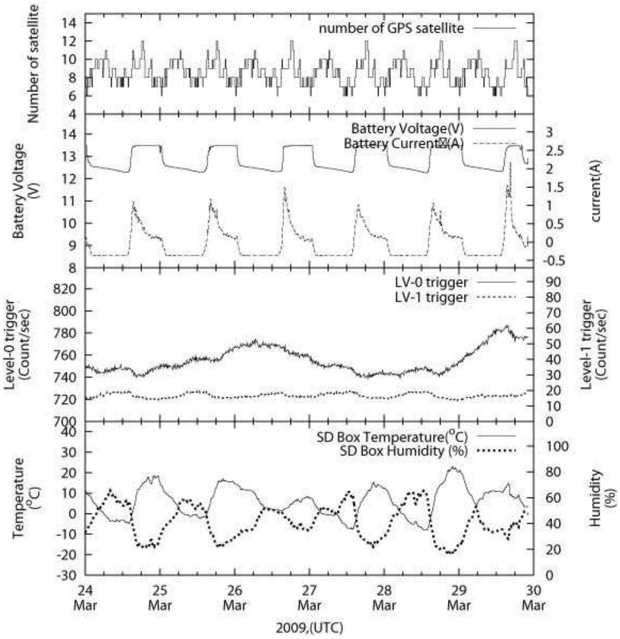

Fig. 5. Examples of monitoring plots, as a function of time, for one surface detector from March 22 to March 30 in 2009 (UTC). The number of detected GPS satellites is shown in the top panel. In the second panel, the solid line is for battery voltage, and the long-dashed line is for battery current. The solid line shows Level-0 trigger, and the dashed line shows Level-1 trigger in the third panel. In the bottom panel, temperature and humidity inside the SD box are shown by the solid and dotted lines respectively.

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