Improved Data Acquisition System for CREAM-III

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Abstract: The CREAM (Cosmic Ray Energetics And Mass) data acquisition (CDAQ) system showed excellent stability and robustness during the 2004/05 and 2005/06 Antarctic campaigns. One improvement for the CREAM-III DAQ system is a redundant Science Flight Computer (SFC), which was a potential single point failure for the previous flights. Another improvement is a high speed USB 2.0 interface between the SFC and the detectors to allow better data collection efficiency. New CDAQ hardware and software for the USB interface were successfully tested during the 2006 accelerator calibration of the CREAM-III calorimeter. The hardware architecture design, software implementation and performance evaluation of the CREAM-III DAQ system are presented in this paper. Our preliminary result shows that the CREAM-III USB 2.0 data acquisition system performs significantly better than the previous, PC/104-based, CDAQ system.

Introduction

Cosmic Ray Energetics And Mass (CREAM) is a balloon-borne experiment flown on long duration balloons in Antarctica to measure the energy spectra and composition of cosmic rays [1,2]. The CREAM data acquisition (CDAQ) system showed excellent stability and robustness, accumulating 70 days of exposure during the 2004/05 and 2005/06 Antarctic campaigns [3]. The CREAM payload consists of the science instrument and flight support systems. The instrument is configured with complementary and redundant particle detectors, a Science Flight Computer (SFC), and common electronics. The NASA flight support systems, including redundant flight computers, power system, telemetry, etc. are enclosed in a separate Command and Data Module (CDM). During the flight, the SFC collects physics, calibration, pedestal and housekeeping events from various detectors, and sends them to an active CDM flight computer for transmission to the ground. The SFC also transfers commands arriving from the ground through the CDM to the instrument command system. Telemetry is sent in flight via the Telemetry and Data Relay Satellite System (TDRSS) to a NASA Engineering Support Center (ESC) and ultimately to a Science Operations Center (SOC) at the University of Maryland. The CREAM-III flight is scheduled to be launched in December 2007. In the first two flights, a simplex SFC was flown, which could potentially have been a single-point failure due to a single event upset (SEU). The SFC architecture was based on the PC/104 bus, providing somewhat limited rate capability. These two limitations have now been addressed in the CREAM-III DAQ system, which employs a redundant SFC architecture based on a high speed USB 2.0 bus. The hardware architecture design, software implementation and performance evaluation of the improved CREAM-III DAQ system are presented in this paper.

CDAQ Hardware Architecture

With flight durations of many weeks, the vulnerability of a simplex SFC to SEUs can be significant, and could lead to loss of instrument functionality. The probability of SEU due to ionizing

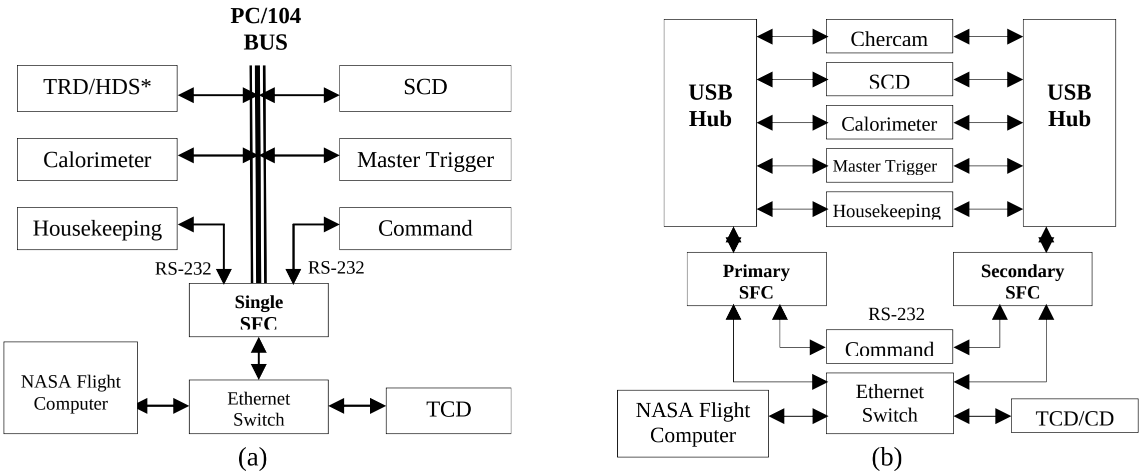


Figure 1: Comparison of CDAQ system architectures (a) CREAM-I/II (*only for CREAM-I) (b) CREAM-III.

radiation is much greater at balloon float altitudes of 37.5 km – 40.5 km than at sea level. This is especially true above Antarctica, where the geomagnetic cutoff energy is much lower, and the flux of ionizing particles much higher, than at equatorial latitudes., A 100-day Ultra Long Duration Balloon (ULDB) mission would require an even more robust and reliable CDAQ hardware/software co-design.

Figure 1 shows the two main differences between the SFC architecture designed for CREAM-III and that used in previous flights. The first is a redundant SFC architecture with standby replacement policy. This architecture maximizes system availability and allows the mission to continue in case of transient or even permanent SFC faults. The redundant architecture increases Mean-Time-To-Failure (MTTF) of the CDAQ system, resulting in better reliability than in previous flights. Another major difference is in the interface between the SFC and the rest of the instrument, using a high speed USB 2.0 interface in CREAM-III instead of the PC/104 interface used before. While the PC/104 interface would require 104 signals to switch active SFCs, the newly implemented USB 2.0 interface requires only 2. In addition to switching efficiency, USB 2.0 allows faster data transfer speed.

CDAQ Software Implementation

The CREAM-III DAQ software was developed for the USB 2.0 interface. The CDAQ software was implemented primarily using the C++ language for modularity and extensibility. With a command interpreter tool (LEX/YACC) translating human-readable science script commands to 8-byte hexadecimal codes or vice versa. A CREAM Graphic User Interface (GUI) program for commanding detectors and monitoring event data was implemented using the Qt Designer tool. The HKVIEW program was also implemented to monitor housekeeping data from the instrument.

CDAQ was designed as a client/server model, with the SFC software as server, and the software running on SOC PCs as client. Figure 2 (a) shows the server processes running on the SFC and memory queues for inter-process communication. The CDAQ_SERV process manages all other processes in the server program. Multi-threading techniques are employed to handle network communications effectively. The CDAQ_SNIO process includes five threads. Two of these, PKT0 and PKT1, are dedicated to fragment science and housekeeping event data, respectively, into data packets small enough to be efficiently handled by the telemetry system. The CS thread sends connection status packets to the redundant CDM flight computers every five seconds. The SFC receives connection acknowledgement packets from the active CDM flight computer and updates the CDM computer IP address as needed.

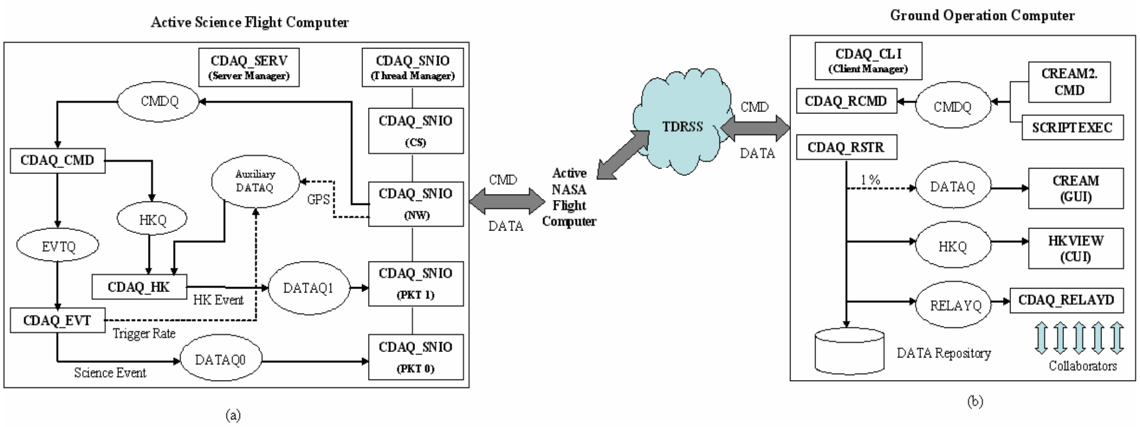


Figure 2: Implementation of CREAM-III DAQ Software (a) Server-side runtime processes, (b) Client-side runtime processes.

The NW thread sends the fragmented data packets to the active CDM computer, receives command packets from it, reassembling and forwarding them to the CDAQ_CMD process. Commands related to the housekeeping system are forwarded to the CDAQ_HK process, which collects the housekeeping data. All other commands are passed to the CDAQ_EVT process, which interfaces to the individual detector systems and builds science event records.
Two operation modes are implemented in the client program: The first is a lab test mode with direct connection between server and client. The second is a flight mode with indirect connection. Figure 2(b) illustrates data flow and client processes in the SOC computer during flight mode operation. The CDAQ_CLI process manages three major processes in the client program, responsible for remote commanding, data forwarding, and data backup/relay functions. Science commands from the CREAM2.CMD or SCRIPTEXEC programs are forwarded to the CDAQ_RCMD process, which sends the command packets to the active CDM flight computer via TDRSS. The CDAQ_RSTR process receives the fragmented data packets, reassembles them and extracts science event and housekeeping data. All data are saved on a local disk and can be relayed to other collaborators through the CDAQ_RELAYD process. Only 1% of all event data is monitored by the CREAM GUI. Housekeeping data are monitored by the HKVIEW program.

Performance Evaluation of CDAQ

The new CDAQ system was successfully tested during the 2006 accelerator calibration of the CREAM-III calorimeter [4]. During the beam test, the CREAM-III DAQ hardware and software, running on a non-flight Beam Test Computer (BTC) system, collected calorimeter calibration events. Data acquisition rates were measured with several instrument configurations during the run. In the following, we define an evaluation metric for the new CDAQ performance based on the raw DAQ rate for event data transfer speed without accounting for data write-to-file time in the client computer.

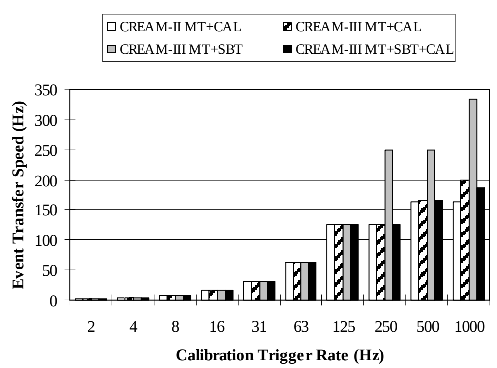
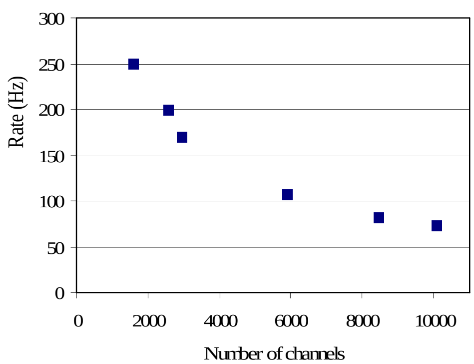
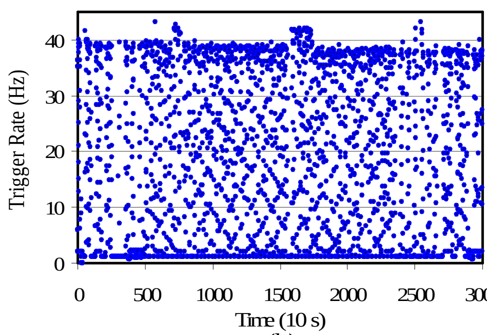


Figure 3: Comparison of DAQ rate performance between CREAM-III and CREAM-II architectures.

Figure 3 compares DAQ performance between the CREAM-III DAQ and the previous architecture, using input calibration frequencies from 2 to 1000 Hz. Four different configurations were considered for these tests. (1) Master Trigger (MT) and calorimeter (CAL) with CREAM-II DAQ, (2) MT and CAL with CREAM-III DAQ, (3) MT and Silicon Beam Tracker (SBT) with CREAM-III DAQ, and MT+SBT+CAL with CREAM-III DAQ. While the event transfer speed of previous CREAM-II architecture with PC/104 interface saturated at 164 Hz, the CREAM-III DAQ reached a rate of 200 Hz. The latter's performance is thus 22% faster than that of the former (for the same number of channels and detectors).



(a)



(b)

Figure 4: CREAM-III DAQ (a) average data readout rate with different number of channels, (b) trigger rate in the beam test.

Given a fixed 1 kHz input calibration trigger rate, a 1000-event run was executed to measure event size and DAQ raw rate while increasing the number of channels by adding more detectors. Figure 4(a) shows the average data readout rates with different numbers of channels and detectors. When all the instruments in the CREAM-III flight configuration are executed the total number of channels is 10,048 and the DAQ raw rate is 74 Hz. Figure 4(b) shows the average trigger rate recorded every 10 seconds in the beam test when reading MT, CAL, top SCD, bottom SCD and SBT. The total number of channels was 8804 and the plot indicates a beam structure with ~4 s beam spills in a ~16 s beam cycle. The DAQ was not saturated at ~40 Hz and we can see the maximum trigger rate decreases from ~40 to ~38 Hz in ~8 hours as the beam intensity decreases.

Summary

This paper presents the upgraded CREAM-III DAQ system, including a redundant SFC architecture, CDAQ software implementation for USB 2.0 interface and its performance evaluation. Our results show the new CDAQ hardware and software design and implementation improves event transfer speed. The new CDAQ stability was successfully tested through the 2006 beam calibration of the CREAM-III calorimeter and the CREAM-III integration and testing for the 2007/08 Antarctic campaign.

Acknowledgements

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