The ATLAS MDT Control System

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Abstract

The muon spectrometer of ATLAS consists of four types of muon chambers of which the Monitored-Drift-Tube chambers (MDT) are in terms of space and readout channels the largest. Its Detector Control System (DCS) can be separated into a CAN fieldbus-based part (temperature sensor readout, magnetic field sensor readout and control of the front-end readout electronics) and a non-CAN fieldbus-based part (gas, high- and low-voltage). This article covers only the first part (CAN). For this purpose each MDT chamber is equipped with a so-called MDT-DCS-Module (MDM), containing a CAN-node. About 1200 chambers are connected to 96 CAN-buses in total, monitored and controlled by a commercial SCADA system (PVSS) running on ten PCs. The data produced by the temperature and magnetic field sensor sub-systems is stored at regular intervals into a database and is mainly used for off-line analysis. The front-end sub-system (FE) initializes and configures the readout electronics. The sub-systems are incorporated into the overall ATLAS Finite-State-Machine (FSM) in order to control it in a general and consistent way. Several tools were developed for maintenance and diagnostics.

INTRODUCTION

The CAN-based part of the MDT-DCS comprises the temperature and magnetic field sensors, as well as the control of the front-end electronics. The sensors, mounted on the chambers, are meant for off-line analysis, in general track reconstruction. The front-end electronics, responsible for the physics readout (DAQ), consists of printed circuit boards directly mounted on the tubes. They are configured using the JTAG protocol and their voltages and temperatures are monitored. After an overview of the hardware and their interconnections, the control part is described.

GENERAL DESCRIPTION

At an early stage in the design phase of ATLAS the CAN-bus using the *CANopen* protocol was recommended as the standard fieldbus to use for distributed control and monitoring tasks. For this purpose a general-purpose plug-on module was developed within ATLAS, called Embedded Local Monitor Board (ELMB) [1], featuring a user-programmable microcontroller, 64 analogue inputs, 24 digital I/Os and a CAN-bus interface. The ELMB has been qualified to work in a radiation environment, as well as in a magnetic field. The ELMB application software can be upgraded in-situ via the CAN-bus. Several thousand ELMBs are applied in the sub-detectors of the ATLAS experiment. It has found application in other LHC experiments as well.

Figure 1: Picture of an MDM (112x60 mm)

In the MDT system every chamber has been equipped with an ELMB mounted on a custom motherboard with appropriate connectors. The box with the ELMB containing MDT specific software has been named MDT-DCS Module or MDM. A picture of it is shown in figure 1. It has connectors for temperature probes (T-sensor 0 to 29), magnetic field sensors (B-sensor 0 and 1; two sensors per connector), front-end electronics voltage and temperature monitoring (CSM-ADC), front-end electronics initialization and configuration (JTAG), and connection to the CAN-bus (two connectors to enable daisy-chaining of modules on a bus). Figure 2 shows the connections of the MDM in a diagram.

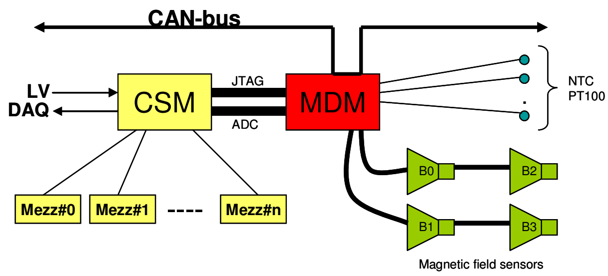

Figure 2: MDM Connection Diagram

The MDT control system consists of 96 CAN buses which connect up to 24 chambers each, interconnected and daisy-chained by a flexible cable. A thick cable (to limit voltage drops) of 100 meters connects the bus further to a power-supply located in USA15 (ATLAS counting room). The in-house developed power-supplies provide power to the MDM and interface the CAN-bus to the PCI-interface cards installed in the PCs. A PCI-interface card from Kvaser is used, capable of handling four CAN-buses. Eight PCs, each with three of those cards installed, monitor 12 buses each. A ninth PC is used as super-visor and a tenth as spare. Two adjacent racks in USA15, one for the crates with the power-supplies and one for the (rack-mountable) PCs, house the MDT-DCS setup.

Temperature Sensor System

Most MDT chambers are equipped with up to 30 T-sensors. The MDT system contains a total of 12,236 T-sensors. After installation 0.5% is out of order. Two different types of temperature sensors are applied: NTC and PT100. The temperature sub-system is used to monitor the temperature distribution within the muon chamber regions which is most of the volume of ATLAS.

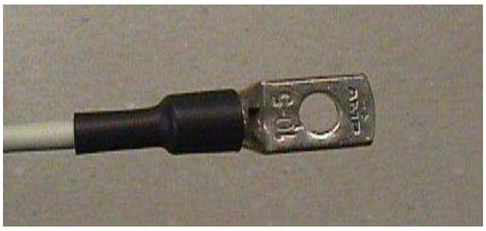

Figure 3: NTC-type T-sensor assembly

Magnetic Field Sensor System

About half of the MDT chambers is equipped with up to four B-sensor modules each, that can measure B-field values in three dimensions with a precision of 10^{-4} and a maximum of 1.4 Tesla. The MDT system contains a total of 1773 B-field sensors. After installation less than 1% is broken. The magnetic field system is used to monitor the magnetic field distribution of the field generated by the ATLAS Barrel and Endcap toroid and central solenoid magnets.

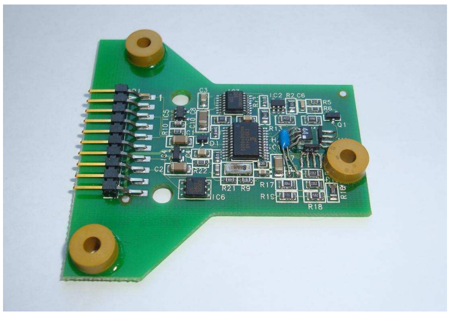

Figure 4: B-field module with 3 Hall sensors

Front-end Electronics

The front-end electronics (FE) of an MDT chamber take care of the physics data-acquisition and consist of a central module called Chamber Service Module (CSM) and up to 18 so-called Mezzanines, as shown in Figure 2. For the DCS system the FE sub-system is sub-divided into its two main parts:

1. *JTAG* (initialization and configuration)
2. *CSM-ADC* (monitoring)

The read-out electronics (CSM and Mezzanines) have their own power, supplied by the low-voltage (LV) system. The MDM has a serial connection to an ADC located on the CSM by which voltages and temperatures on both CSM and Mezzanines are monitored. In total 14,236 Mezzanines are applied. In addition the MDM has a JTAG interface to the CSM which is used for initialization and configuration of the front-end electronics. Configuration parameters are read by a host system from a database and sent in the form of JTAG instruction and data bit sequences across the CAN-bus to the MDM which then uploads them into the front-end electronics.

NB: The numbers given are not final, but a snapshot taken during the summer of 2009. Not all MDT chambers are installed yet, so the numbers will increase. The percentage of faulty devices is stable. Many of the faulty sensors cannot be replaced or repaired anymore, because they are not accessible. In most cases the sensor is not broken, but the cable or connector got disconnected or damaged.

CONTROLS

PVSS II, a commercial SCADA (Supervisory Control And Data Acquisition) product by ETM [3], is chosen by CERN for all LHC experiments. PVSS supports the typical SCADA functionality, like archiving, alarm handling, man-machine-interface and data acquisition. Its main characteristic is the *datapoint* concept, the basic data-container of a variable which could be everything from being a simple type (integer, float, etc) or a complex type like an array, structure or a reference to another datapoint. Each sensor or ADC channel has a corresponding datapoint defined in the PVSS system. The actual values are read at regular intervals by an in-house developed CANopen OPC-server, which acts as the gateway between the hardware and the datapoints. In this respect PVSS may be regarded as the OPC-client

An important aspect of the MDT-DCS is the use of databases (at CERN Oracle is used). One of the primary tasks is to store the sensor and ADC values of the CSM to the *Conditions* database, which is used by the off-line analysis (in particular track reconstruction). Several tables are defined. The time-stamp column and chamber column are used as combined primary key. Another database is the *Configuration* database. It contains for each chamber the most important parameters, like the node address and serial number of the MDM, the number of temperature and magnetic field sensors, the number of Mezzanines, the calibration constants of the PT100 sensors, etc. Regenerating the entire PVSS project requires this information. It also contains the JTAG parameters, so during normal operation it is consulted as well.

Five logical devices can be distinguished: node, temperature, magnetic field, CSM-ADC and JTAG. For each of them a state per chamber is maintained. The node state reflects the global functioning of the MDM and whenever there is no 'heartbeat' or the MDM transmits error messages concerning the node itself, its state is set to `dead` or `error` and as a consequence the other substates below are set to `unknown`. If `okay` however, the other states are set according to the quality of their data, e.g. if the values are not updated anymore, the state is set to `dead`. For each sub-system a specific set of states exist, but they have states `okay`, `unknown` and `dead` in common. A dedicated control manager (*Watchdog*) takes care of handling the emergency messages and determination of the states and status.

The temperature, magnetic field and CSM_ADC sub-systems are rather straightforward, i.e. read, convert and store. The JTAG sub-system is the only one capable of handling commands. The main command is to initialize and configure the front-end electronics by means of bit-strings using the JTAG protocol. It is used to set several parameters inside the Mezzanines. An operator may decide to initialize a single chamber, a sector or the whole MDT sub-detector. The JTAG strings are generated by a dedicated control extension (a PVSS supporting dynamic link library), which consults the Configuration database. The strings are transmitted serially to one chamber on the CAN-bus at a time. This increases the initialization time of the MDT chambers considerably. Including the reset of the CSM (2 seconds), the time needed to initialize one chamber is around 7 seconds. To increase the speed, each CAN-bus has its own manager to take care of the initialization, so that the initialization can take place on 12 buses in parallel, which makes the total time of initialization depending on the bus with the largest number of chambers. For the MDT sub-detector it means that a full re-initialization takes about 10 minutes. The state and status of the JTAG sub-system is determined by the initialization manager and certain fault conditions caught by the Watchdog manager. Figure 5 shows the state diagram and transitions.

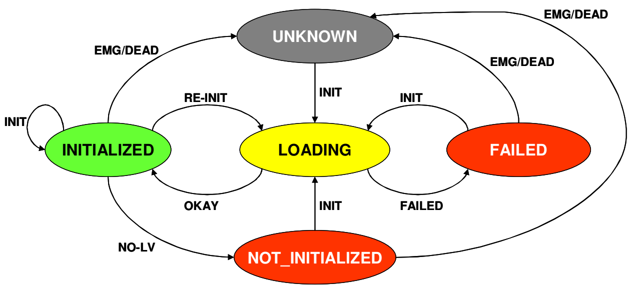

Figure 5: Initialization state transition diagram

Inside the global MDT-FSM tree for each sub-system (T, B, CSM-ADC and JTAG) a state of each chamber exists. The chamber defines the *granularity* and holds the Device Unit (DU). The hierarchy is sub-system based and towards the lower parts a more geographical division is used of which the top always differentiate into the four main parts of ATLAS; i.e. Barrel A- and C-side, Endcap A- and C-side. The super-visor PC takes care of the top and intermediate levels of the tree, i.e. the Control Units (CU). Figure 6 shows a slice of the JTAG-FSM tree.

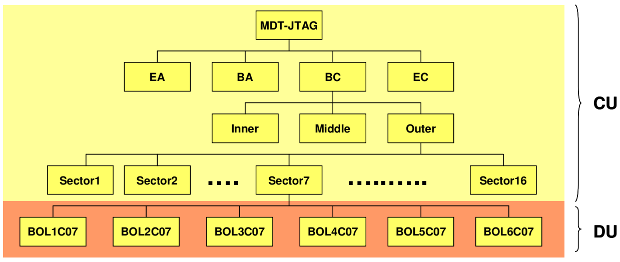

Figure 6: JTAG FSM hierarchy

STATUS & CONCLUSION

The MDT-DCS system is now in use for more than a year and its operation from the ACR (ATLAS control room) has become daily practice. To date, the data-gathering sub-systems (temperature, magnetic field and CSM-ADC) collected several hundreds of GBytes of data. During the magnet tests the magnetic field readout system provided sufficient data to produce high quality field maps. The JTAG sub-system is used in combination with the low- and high-voltage system, because together they define whether a chamber is ready to take data or not. Although the time to initialize the front-end electronics of the chambers is not a major issue, efforts are taken to decrease it.

A useful debugging tool is the *CANspy* module [4]. The auxiliary output of all CAN-bus power supplies is connected, in order to select any CAN-bus and to monitor/spy without disturbing PVSS or the DCS system.

Every night a summary is created containing the power consumption of the CAN-buses, the failure rate of the JTAG initialization and the number of lost temperature and magnetic field sensors. The summary is stored into the database and is accessible via a web interface.

PVSS has proven to be reliable and scalable. Handling several thousands of datapoints is no problem. Also its distribution capability between the projects is powerful. The in-line call-back functionality, by which an automatic 'simple' calculation is performed on change of a datapoint value, was used extensively. It decreased the performance considerably and the functionality is taken over by the Watchdog manager. A disadvantage of the scripting language is that errors due to undefined variables are only discovered at runtime, which may potentially crash (part of) the PVSS system

REFERENCES

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