The Detector Control System for the magnetic field sensors in New Small Wheel phase I upgrade of ATLAS detector

Tzanos Stamatios
National Technical University of Athens

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Introduction
LHC is CERN’s particle accelerator:
- collides pp beams at 176m under the surface
- 27km circumference
- hosts 1232 dipole and 392 quadrupole magnets
- 4 collision points: ATLAS, CMS, ALICE and LHCb

LHC is undergoing an upgrade to HL-LHC:
- Before shutdown:
  - 13TeV centre-of-mass energy
  - Integrated Luminosity: ~350fb\(^{-1}\)
- After upgrade:
  - 14TeV centre-of-mass energy
  - Integrated Luminosity: ~4000fb\(^{-1}\)

For this purpose, detector experiments also undergo upgrades in search for new physics.
New Small Wheel

NSW will be able to handle the HL-LHC significantly larger data rates with specifications:

- Precision tracking acceptance of $1.3 < |\eta| < 2.7$
- Track segment reconstruction with angular resolution of 1 mrad or better at the Level-1 Trigger
- Muon track reconstruction resolution of 40 μm
- Muon online track reconstruction efficiency $\geq 95\%$

NSW is expected to replace the Small Wheel in ATLAS during 2021.
Installation of first side A sector in Dec. 2019
The ATLAS Toroid Magnet System

The Toroid Magnet System of ATLAS consists of **1 Barrel Toroid** and **2 End Cap Toroids** for particle separation:

- ~ 0.8T average in Barrel Toroid torus
  - 3.9T peak in windings
- ~ 1.3 T average in End Cap Toroid torus
  - 4.1T peak in windings

*Effect on NSW must be considered and measured → BField sensors*
The ATLAS Toroid Magnet System

Barrel Toroid magnet

End-Cap Toroid magnet

Image from Roger Ruber’s presentation: “ATLAS The World’s Largest Magnet System”

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Hardware for magnetic field monitoring in NSW
Installed MDMs can be uniquely identified by their ID and Serial Number

Readout with ELMB (Embedded Local Monitor Board)
MDM (MDT-DCS Module):

- **User programmable microcontroller**
- Analog/Digital connectors
  - **B-Field sensors**
  - T-sensors
  - CSM-ADC
  - JTAG interface
  - **CAN-bus interface**
The B-Field sensor

- 3 Hall effect magnetic field sensors
- 1 NTC thermistor
- 24-bit ADC
- ID-chip
- 10-pin IDC flat cable connector

Readout

- Write `bfMask` item using the CANOpen protocol

|                | Data Byte 0 | Data Byte 1 | Data Byte 2-4 |
|----------------|-------------|-------------|---------------|
| MDT-DCS module | Channel number | ADC-config | 24-bit ADC value |

- **None** or up to 4 Bfield sensors can be monitored at the same time
- **Read** the B-Field ADC value as a PDO message from MDM
Hardware for magnetic field monitoring in NSW

**How many for NSW?**

- 12 B-Field sensor/Large sTGC Double Wedge
  - 96 B-Field sensors/side
  - → 192 B-Field sensors in total
- 4 MDMs/Large sTGC Double Wedge
  - 32 MDMs/side
  - → 64 MDMs in total

**What about connection mapping?**

- MDMs are mapped according to their side on spoke
- B-Field sensors are mapped according to their labels and positions on sector
The B-Field sensor testing setup
The B-Field sensor testing setup

What is happening in here? (Answer in next slide)

The hardware:
- MDM module
- PCB with 10-pin IDC flat cable connectors
- 10-pin IDC flat cable with two connectors in series
- B-Field sensors to be tested
- Terminal Resistance of 180Ω
- CANbus cable (MDM – Power Supply)
- CANnode Power supply 8 – 12V
- CANbus cable (Power Supply – Sys Tec)
- Sys Tec box USB – CAN with 2 modules and 125000 bitrate
- Laptop with the DAQ system and DCS
With a configured mask, the DCS:
- reads information about the MDM
- reads information about communication/power
- tests the data acquisition from Sys Tec
- displays ADC data and Trends
The B-Field sensor testing setup

Use of the Testing DCS (Building 180 at CERN):
1. Starting OPC UA server
2. Running the DCS Panel
3. Inspecting the B-Field sensor connectivity/data

Test of the BField sensors on the test bench and on the wedges after installation

95/96 side A BField sensors were successfully tested before moving the sTGC sectors to Building 191 (commissioning site)
Commissioning site DCS
Side A: 16/16 sectors are successfully connected and are being commissioned.

Side C: 3/16 sectors are successfully connected and commissioning will begin soon.

*Side A is expected to be installed in ATLAS cavern in the middle of July, 2021.*
Wheel MDMs are monitored in quadrants:
- 8 MDMs per CANbus daisy chain
  - 4 MDM daisy chains (noted by different colors)
- 1 CANbus to USB cable per daisy chain
  - 2 Sys Tec boxes with 2 CANbus inputs per wheel
After configuring all of the MDMs on the wheel:
- Ability to monitor each sector individually
- Readout provided for each MDM
- Sensor data display as well as connectivity

Debugging
- Recognize sensors that are malfunctioning
  - disconnected IDC cables
  - non nominal NTC thermistor readout
- Re-crimping of connectors
- Low-level inspection of MDM configuration

For Side A 93/96 sensors were successfully commissioned
ATLAS Point 1 DCS
sTGC MDM readout at P1 will be connected to MDT machines for readout
Copy mechanism to pass datapoints to BField project

Similar with the MDT projects’ datapoint structure with some modifications

**Data structure**
- The 16 ADC values read out
- The 16 config bits read out

**Sensor structure**
- Information about sensor mapping
- ID of the sensor
- x3 Hall int values + Temperature in mdeg
- $B_x, B_y, B_z$ computed from $H_1, H_2, H_3$
- Calibrated value of the B-Field
- Connectivity status and states

How will all these be updated?
- MDT Watchdog (📸) will receive data
- Copy Mechanism to BField project
ATLAS Point 1 DCS

Computations for the B-Field sensors:

- **ADC values** → $H_1, H_2, H_3$ using the 24-bit uint to int conversion
- $H_1, H_2, H_3 \rightarrow B_x, B_y, B_z$ using the Saclay calibration constants from the Database
- B-Field value:
  \[ B_{cal} = \sqrt{B_x^2 + B_y^2 + B_z^2} \]

- **Sector average** from N connected sensors:
  \[ \bar{B}_{cal,sector} = \frac{1}{N} \sum_{i=1}^{N} B_{cal,i} \]

- States

Next page
DCS Design

For the final project at P1:
➢ No Alarms will be used
➢ B-Field sensors will reserve a place in Expert Panels

For visualization reasons, state colors following the ATLAS convention are used:

- OK
- WARNING
- ERROR
- FATAL

Currently arbitrary ranges are being used. To be decided and computed accordingly.
MDM View

Sensor View
Future goals
Future goals

1. Building 191 Commissioning
   - Try to repair sensors that are malfunctioning
   - Commission C side sensors

2. Graphical User Interface
   - Display MDM power statuses
   - Select proper representations for expected value ranges

3. Point 1 Integration
   - DCS currently uses random ADC values → Get DPs from MDT machines using the copy-mechanism
   - Commission DCS at Point 1 correctly using Central DCS Guidelines
Thank you for your attention.

... questions?
BACKUP
New Small Wheel

(a) sTGC (small sector).
(b) MM (small sector).
(c) sTGC (large sector).
(d) MM (large sector).

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| bfMask Dec | bfMask Hex | Layout                                      |
|------------|------------|---------------------------------------------|
| 0001       | 0 × 1      | 1 sensor at input 0                         |
| 0010       | 0 × 2      | 1 sensor at input 1                         |
| 0011       | 0 × 3      | 2 sensor, 1 at input 0 and 1 at input 1     |
| 0100       | 0 × 4      | N/P                                         |
| 0101       | 0 × 5      | 2 sensors at input 0                        |
| 0110       | 0 × 6      | N/P                                         |
| 0111       | 0 × 7      | 3 sensors, 2 at input 0 and 1 at input 1    |
| 1000       | 0 × 8      | N/P                                         |
| 1001       | 0 × 9      | N/P                                         |
| 1010       | 0 × A      | 2 sensors at input 1                        |
| 1011       | 0 × B      | 3 sensors, 1 at input 0 and 2 at input 1    |
| 1100       | 0 × C      | N/P                                         |
| 1101       | 0 × D      | N/P                                         |
| 1110       | 0 × E      | N/P                                         |
| 1111       | 0 × F      | 4 sensors                                   |
CANbus communication