TileCalorimeter: Monitoring of the LTC2980 Chip for the HL-LHC Upgrade Using PyQt6 GUI

Summer student report

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Abstract

The Large Hadron Collider is comprised of four detectors scattered around its perimeter which are the following ATLAS, CMS, ALICE, and LHCb. The ATLAS detector and its collaboration which is the biggest among the four detectors will be hosting my and supervising my summer student project. The project revolves around the Tilecalorimeter, within the ATLAS detector, specifically the CPM(compact processing module). The task is to monitor the input voltage, output voltage, temperature and output current of the LTC2980 chip inside the CPM. Monitoring the chip in real time we use PyQt6 GUI to properly visualize the monitored parameters.

Contents

1 Introduction

1.1 Overview of the ATLAS Detector

The ATLAS detector is considered to be the biggest among the four detectors located at the perimeter of the LHC. Given its size it also boasts the largest collaboration within CERN. The ATLAS detector is consists of the inner detector, the muon spectrometer, the magnet system and the calorimeters. An image of the ATLAS detector can be seen below as Figure 1 [1]

The inner detectors is responsible for reconstructing the tracks and vertices of any events that detected inside of it. It is consisted of 3 more layers: the pixel detector(each pixel is as small as a grain of sand capable of detecting up to 10 μm of precision), the semiconductor tracker(responsible for reconstructing the tracks and vertices of the particles detected by the pixel detectors during collisions), and the transition radiation tracker(capable of identifying what type of particle has just passed through the detector). You can see the inner detector as was shown in Figure **??** .

The muon spectrometer, as was shown in Figure 2b, detects the presence of muons, a lepton similar to an electron, and also determines the particle's momenta. It is usually located at the far end of the detector due to the muons capability to pass through the thickness of the ATLAS detector. The muon spectrometer uses 5 different tecnhonologies to detect the presence of the particle. These technologies include the Resistive Plate Chambers, the Thin Gap Chambers, the Monitored Drift Tubes, the Micromegas, and the Small-Strip Thin Gap Chambers. Two of these (Micromegas and sTGCs) are designed for the upcoming upgrade of the LHC, the HL-LHC.

The magnet system bends the charges particles produced from a collision allowing allowing the detector to measure its momentum and charge. The magnet comes into two shapes- a toroidal and a solenoidal magents. The solenoidal magnets main responsibility is to bend the particles trajectory allowing the detectors to measure its momenta and charge. The toroidal shaped magnets is mainly for the measurement of the muons momenta. These two magnet systems is constantly being cooled to maintain superconductivity. Figure 2c shows the visualization of the magnet system in the ATLAS detector.

Lastly, the calorimeters are the taking/absorbing the majority of the particle for it to deposit the energies after collision. They are made of materials with high density to be able to stop the particles. The deposited energies are then read and analyzed through the electronics connected to the calorimeter. There are two types of calorimeters inside the ATLAS detector, the Liquid Argon(LAr) calorimeter and the Tile Hadronic Calorimeter. The Liquid Argon calorimeter measures the energy of the electron, photon and hardrons while the Tile Hadronic Calorimeter measure the hadrons that wasn't able to deposit all of their energies on the LAr calorimeter. The LAr calorimeter is made up of layers of metals with sandwiching liquid argon. The Tile calorimeter on the other hand is made of steel plating layers with plastic scintillators to measure the particles energies [1]. The image given by Figure 2d shows the calorimeter part of the detector.

1.2 HL-LHC Upgrade

The LHC has been operational since 2008 has been running since the present. It has a current maximum luminosity of $1\times10^{34}(cm^2s)$. In the years of its run it has achieved an integrated luminosity of about 160 fb^{-1} in 2018 and is expected to have an integrated luminosity of about 300 fb^{-1}. This means millions and millions of collisions have been detected and recorded by the different detectors surrounding the LHC. Achieving its greatest triumph by detecting the Higgs Boson on 2012 which completed the Standard Model we now know today, the LHC is still far from reaching its full purpose. It now paved the way for searches for rare events and also searches for particles beyond the Standard Model and in order for us to obtain the desired results we need to upgrade the LHC such that the number of collisions we detect increases by orders of magnitude.

[1] https://cds.cern.ch/record/1095924/

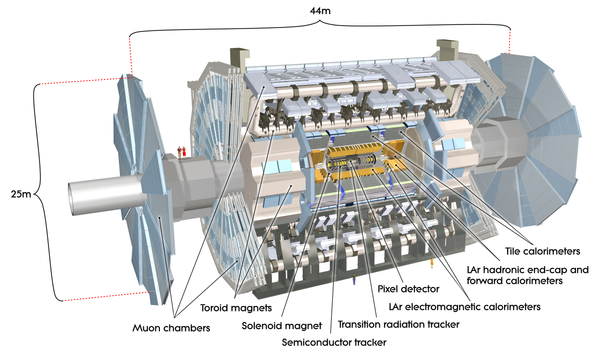


Figure 1: Visualization of the ATLAS detector

The high luminosity upgrade for the LHC or the HL-LHC upgrade is geared towards increasing the amount of collisions happening in the LHC. The upgrade has the goal of increasing the peak luminosity of about $1{\times}10^{34}(cm^2s)$ and an integrated luminosity of about $4000fb^{-1}$ by the end of its run[2]. The upgrade for the LHC has been approved and greenlighted by the CERN council last 2016. Majority of the upgrades will be installed in 2024-2027 but has already started on some equipment as early as 2020. This upgrade is with the high hopes that it can make another breakthrough after more than a decade after the discovery of the Higgs Boson. The great number of collisions will be wasteful if the detectors don't even take the same amount of data, thus, not only the LHC will be getting an upgrade the corresponding detectors will also be upgraded to match the new capabilities of the HL-LHC.

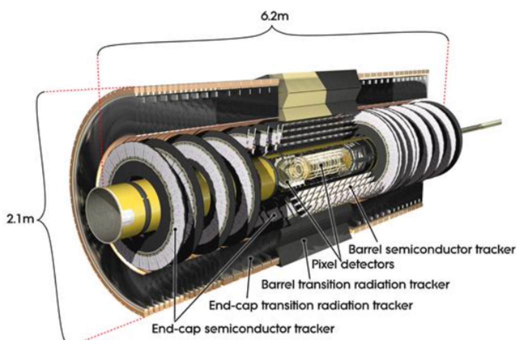
2 Project under the Tile Calorimeter Team

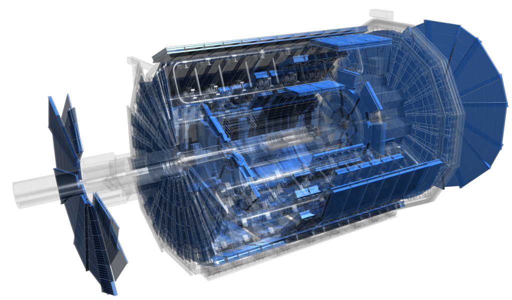
2.1 Tile Hadron Calorimeter

The Tile Hadronic Calorimeter of the ATLAS detector surrounds the LAr Calorimeter and has the main responsibility to absorb and measure the energies of the hadrons that has escaped the LAr calorimeter. These hadron particles comes into contact to the steel plating which results into showering of new particles. The hadron calorimeter absorbs all of these new particles and measure its energies allowing for the reconstruction of the original particle where these new particles originated from.

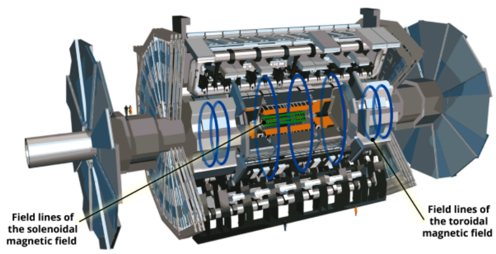
2.1.1 Structure

The hadron calorimeter is made up of 64 modules lined up along for each 3 barrels that surrounds the LAr calorimeter as was shown in Fig 2d below. The central barrel and the extended barrels has lengths of 5.8 meters and 2.6 meters, respectively. Each module of the hadron is made up of steel and plastic scintillators arranged in a periodic positions to optimize the coverage of the whole azimuthal range. The plastic scintillators on each module produces photons as particles pass through it each scintillators are then connected to a photomultiplier amplify the lights coming from the scintillators and then converted into electrical currents that is then read out by the electronics connected to it. The intensity of the light is proportional to the particles energy.[1]

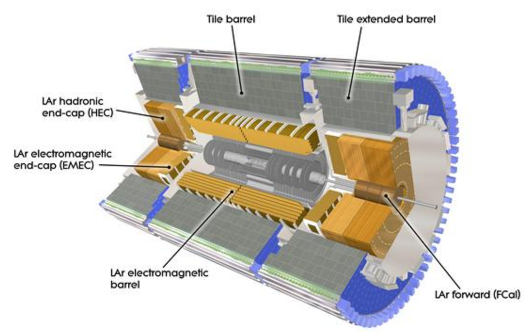




(b) Muon Spectrometer



(c) Magnet System



(d) Calorimeter

Figure 2: a) Inner Detector b) Muon Spectrometer c) Magnet System d) Calorimetry

2.2 My Project

2.2.1 Electronics

With the upgrade starting, not only the LHC itself will get an upgrade but also the detectors involved as well. The ATLAS detector among the other detectors like CMS,ALICE and LHCb are also readying for the additional upgrades as soon as the LHC upgrades starts. Specifically the Tile Calorimeter team of the ATLAS detector has some planned upgrades for the detector. One of upgrade related to this is the electronics for reading the signals detected by the detectors. There are 2 main set of electronics in the ATLAS detectors the on-detector electronics and the off-detector electronics. The on-detector electronics shaped and amplifies the signal detected in the detector specifically in the Tile Calorimeter with the use of Photomultitpliers (PMT) and transmit the data through the high-speed optical modules to the off-detector electronics. In the current Tile calorimeter electronics the data is being processed on the on-detector electronics before being sent off to the off-detector electronics for every bunch crossing which approximately 25 nanoseconds. The upgrade on the electronics will remove the processing on the on-detector electronics and move it on the off-detector electronics.[2]

Both the on-detector and off-detector electronics is composed of different parts that performs its tasks. As for the off-detector electronics a part of it is composed of a CPM (Compact Processing Module) which is based on a FPGA(Field Programmable Gate Array). This allows our CPM to be programmable to handle signal processing, monitoring and data acquisition. The summer student project that I handled is connected to the off-detector electronics of the Tile calorimeter to be precise a part of the CPM. Inside the CPM, a small chip (LTC2980) monitors parameters like voltage and current going to the main chip (Kintex UltraScale FPGA), which is mainly responsible for performing custom signal processing, enabling further analysis. My summer student project is centered around the LTC2980 chip and its monitoring tasks.

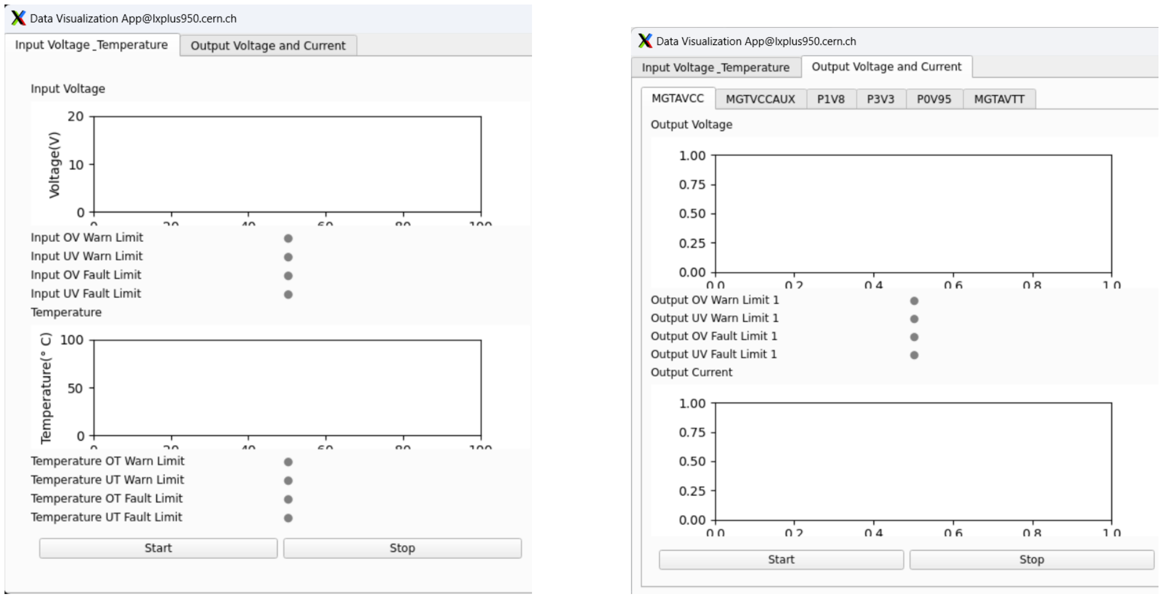
2.2.2 Project Specifications

The main idea of my project is to plot the following parameters voltage, current and temperature of the LTC2980 chip as a tool for monitoring the status of the module. LTC2980's main role is to manage the power going in the main chip/processor. It is a 16 channel power system manager that can trim, sequence, supervise and manage faults.[3] This includes turning off the power system if it exceeds maximum threshold set-up by the user as to not damage the main processor but this was not included in my project. The main task given to me is to make an application that visualizes the input voltage, output voltage, output current, and temperature and to make an alarm mechanisms for each when it triggers certain thresholds. In properly monitoring said parameters I made a GUI using PyQt6 a common module in python for making simple applications.

2.2.3 Project Output

For my project I made an application that monitors the input voltage, output voltage, output current and temperature. In communicating with LTC2980 chip, we need to go through the FPGA processor with the use of the IPBus. IPBus is a communication protocol designed to communicate with electronics. After communicating with the FPGA, the FPGA will then send commands to the LTC2980 chip and receive data from it using the I2C protocol.

I used Matplotlib to visualize the incoming data from the LTC2980 chip, plotting and graphing the necessary parameters for the project. I made a GUI using the PYQt6 library to properly manage the data plots from the LTC2980. In this GUI it has a start and stop buttons that commands the application when to start and stop taking data as shown below in Figure 3. In the LTC2980, register addresses correspond to specific functions or configurations within the device. The datasheet for the LTC2980, which details these register addresses, is available online. To give an example, the register address for reading the input voltage in the LTC2980 is different to the register address for reading the temperature. Calling the proper register address is necessary to perform specific tasks. In my project we only dealt with the register addresses related to the voltage, current and temperature.



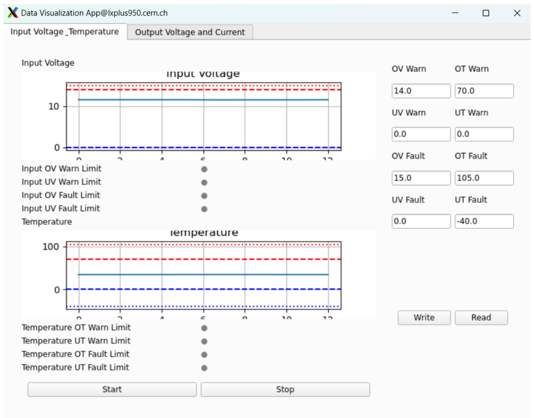
(a) (b)

Figure 3: a)Interface for the Input Voltage and Temperature b)Interface for the Output Voltage and Output Current

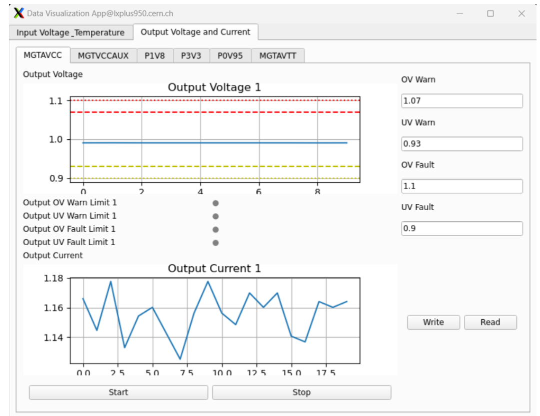
In the application there are two tabs that monitor different parameters, the 1st tab includes the input voltage and temperature and the 2nd tab includes the output volage and output current. They are separated in that way given that the input voltage and temperature is not paged unlike the output voltage and output current. "Paged" means that the register is divided into multiple pages with each page has a subset of registers. These pages corresponds to specific channels in the LTC2980 while non-paged registers gives global command to the LTC2980. You will be able to notice in the previous image that for the output voltage and output current there are several subtabs that corresponds to each of the pages involved.

Aside from the real time plotting of the data from the LTC2980, the application has also an alarm mechanism for certain thresholds. The different thresholds has also specific register address for each parameter. In the case of the input voltage the alarm goes off for the overvoltage warn limit, undervoltage warn limit, overvoltage fault limit and undervoltage fault limit. The warn limit threshold suggests that the parameter is nearing the critical threshold which is the fault limit. This is the same for the temperature, output voltage and output current. Those are only for the reading capability of the application. The LTC2980 can be also written. The threshold limits can be varied depending on the necessary adjustments. There are default values for each limit thresholds for each parameters. Varying these threshold limits means writing on the chip itself. Looking at the application again, we can see the write and read button for each parameters as shown in Figure 4. As you can see each parameter has a set of empty spaces where you can write the new value of the threshold limits depending on the user. Pressing the write button will overwrite the value of the threshold limits on the LTC2980 with whatever is on the spaces. As for the read button, it will show on the spaces the current value for the threshold limits and will display it on the plots as a lines as was shown in the previous image.

From the image above you will be able to see that there is no threshold limit set for the output current, this is due to the lack of the register address for that specific task in the LTC2980. This



(a)



(b)

Figure 4: a)Read and Write for the Input Voltage and Temperature b)Read and Write for the Output Voltage

concludes the summer project that I worked on for the month of August. The completed project is uploaded on github.

3 Conclusion

For the summer student project, we were able to produce an application that monitors the following parameters input voltage, output voltage, temperature and output current. The application was made using the PyQt6 module in python giving us an interface where we can see the data coming from the LTC2980 plotted in real time. In the application an alarm system was also set-up around certain thresholds. The threshold limits on the LTC2980 can be read and written over as a feature of the application.

References

[1] J. A. Valero Biot, *The Back-End Electronics for the ATLAS Hadronic Tile Calorimeter at the Large Hadron Collider*. Doctoral thesis, Universitat de València, Valencia, Spain, January 2014.

[2] F. Carrio, "Design of the compact processing module for the atlas tile calorimeter," *IEEE Transactions on Nuclear Science*, vol. 68, no. 8, pp. 1944–1951, 2021.

[3] I. Analog Devices, *LTC2980 Datasheet*, 2016. `https://www.analog.com/media/en/technical-documentation/data-sheets/ltc2980.pdf`.