Control and Monitoring of Alignment Data for the ATLAS Endcap Muon Spectrometer at the LHC

Overview

The ATLAS Muon Spectrometer is constructed out of 1200 drift tube chambers with a total area of nearly 7000 square meters. It must determine muon track positions to a very high precision despite its large size necessitating complex real-time alignment measurements. Each chamber, as well as approximately 64 alignment reference bars in the endcap region, are equipped with CCD cameras, laser sources, and LED-illuminated masks which optically link chambers and bars in a three dimensional grid. This permits micron–level determination of chamber-to-chamber positions and chamber distortions. This information is used to correct drift tube positions and shape for muon track reconstruction. The endcap optical system produces about 8000 83 kB images during each 20 minute readout cycle.

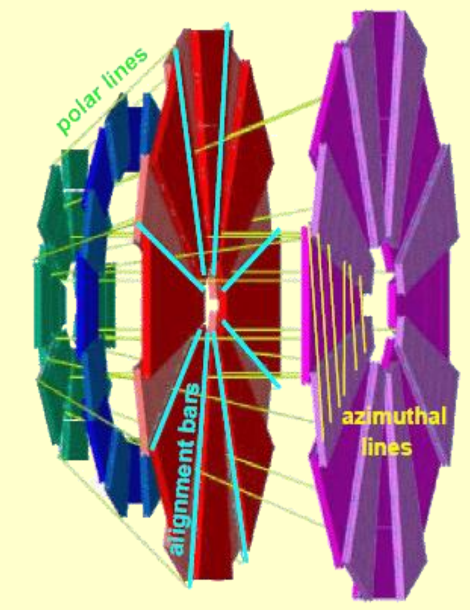
The optical data acquisition and measurements are performed by a hardware/software system called the Long Wire Data Acquisition system – the LWDAQ – developed at Brandeis University by Kevan Hashemi.

Overall control of the system, monitoring of the readout processes, evaluation of validity of images and error conditions, and display and storage of analysis results are performed by a combination of PVSS SCADA-based user interface and separate Linux-based control process developed at the University of Washington under the direction of Joseph Rothberg.

Communication between the PVSS panel and the control process is via DIM – a CERN protocol for Distributed Information Management.

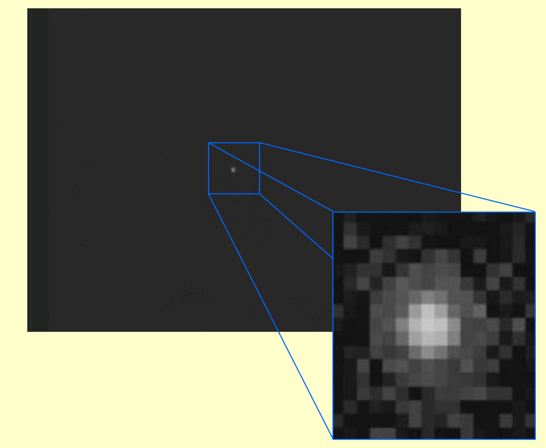
Reconstruction of the positions and orientations in space of the spectrometer components is performed by the "Alignment Reconstruction and Simulation for the Atlas Myon Spectrometer" software – ARAMySS – developed by Christoph Amelung of CERN.

The Hardware System



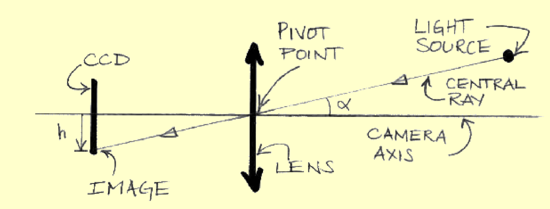
Alignment Bars monitor deformations and thermal expansion. Polar BCAMs align wheels to wheels; azimuthal BCAMs align bars within wheels; RASNIKs align chambers to bars; in-chamber RASNIKs measure chamber deformations; in-bar RASNIKs measure alignment bar deformation and temperature sensors measure thermal expansion.

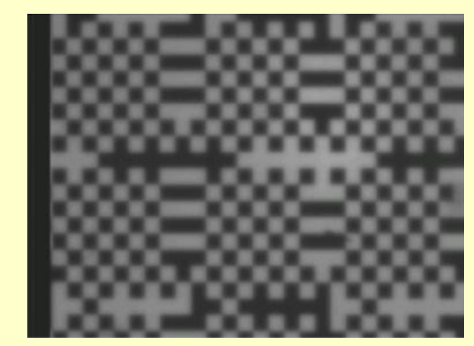
Data is gathered by the control and measurement system (PVSS, LCX and LWDAQ). The sensor data is used by the reconstruction system (ARAMySS) to determine the positions of the muon spectrometer components. The results of the reconstruction are used by the offline track reconstruction.



Angular Measurements

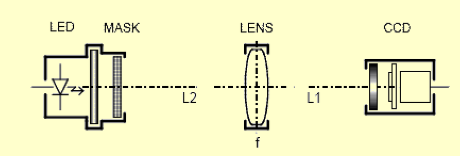
The BCAM system produces images of solid state laser light sources which are then used to make angular measurements. The light sources appear as spots on the images as shown to the left. The centroids of the spots are calculated and bearings to the light sources are determined. These angular measures are used in to help determine positions of the muon spectrometer components.





Proximity Measurements

The RASNIK sensor illuminates a coded mask using a light source. The mask is focused onto a CCD by a lens. Using position information encoded into the pattern on the mask, the position and rotation in the X and Y directions are measured. The Z dimension can be determined by the magnification of the pattern.



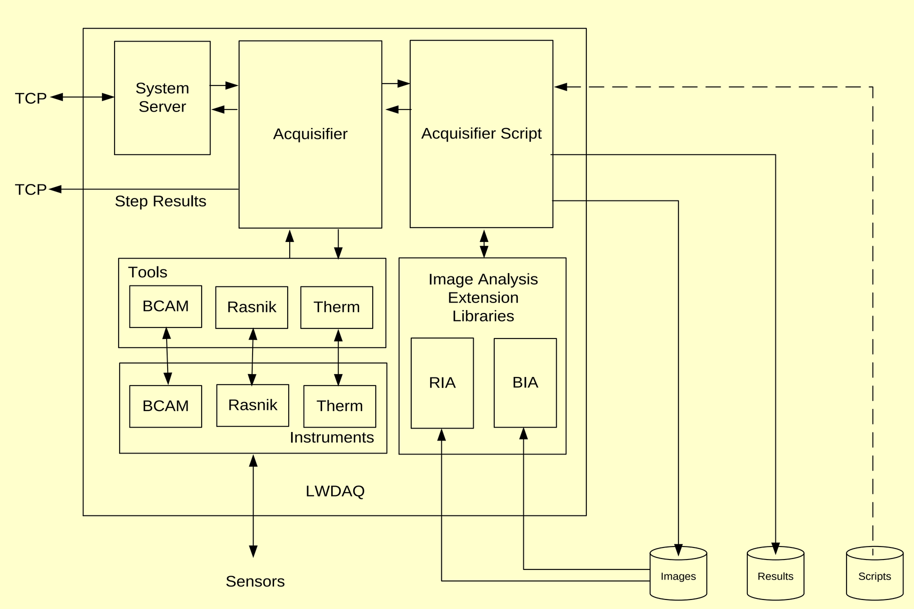
The Long Wire Data Acquisition System (LWDAQ) is used to connect the BCAM and RASNIK devices to the computers that will perform the measurements. The phrase "long wire" refers to the CAT-5 networking cables used as interconnects which can be as much as 100 meters in length.

The LWDAQ software talks to hardware drivers. Drivers may be connected to multiplexers, repeaters or measurement devices. Up to 16 devices may be connected to a multiplexer. Repeaters may be configured to repeat single or multiple devices.

Power for the alignment devices is provided through the cables from the repeaters and may be switched under software control.

A number of devices are available for the LWDAQ hardware. We use the BCAM, RASNIK and temperature devices in the endcap alignment system.

The LWDAQ Software



There are currently two dedicated computers running six LWDAQ data analysis software processes.

The LWDAQ software is written in Tcl/Ik and has a local user interface, but may also be controlled remotely.

The LWDAQ software manages measurement devices under control of an "Aquisifier" system. The Acquisifier supervises the execution of Tcl-based scripts that control each step of the actual measurement process. One "step" corresponds to a measurement made by one device (BCAM, RASNIK or thermometer).

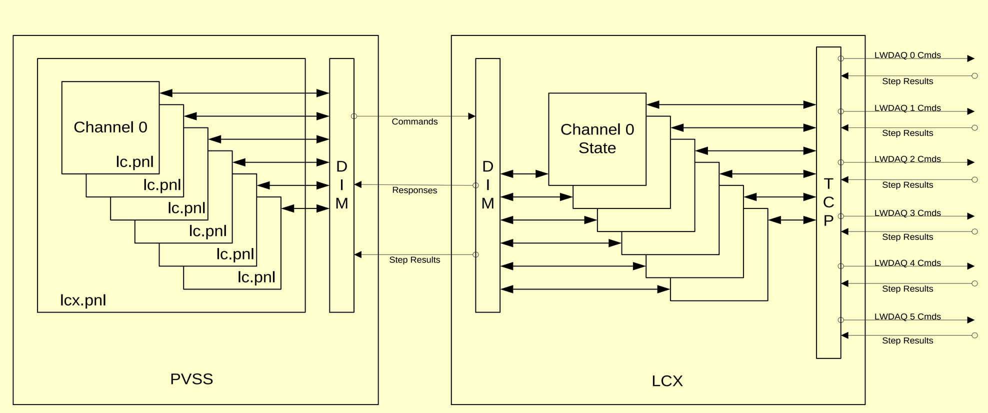
In the online system, the loading and execution of the acquisifier scripts is controlled remotely via a "system server" port and results of each step result can be sent via TCP/IP to a controlling process.

As script steps are executed and measurements are completed, an image quality test is performed. The Tcl acquisifier script calls into image analysis libraries which examine each acquired image for reasonableness.

For example, the BCAM images are checked to make sure there is sufficient contrast in the image and that there is one spot of reasonable size. For RASNIK images, the contrast is checked and the number and sharpness of edges in the mask is evaluated.

If the image quality analysis succeeds, the results of a device measurement are saved in an Oracle database for use in alignment reconstruction using ARAMySS.

The Control Software



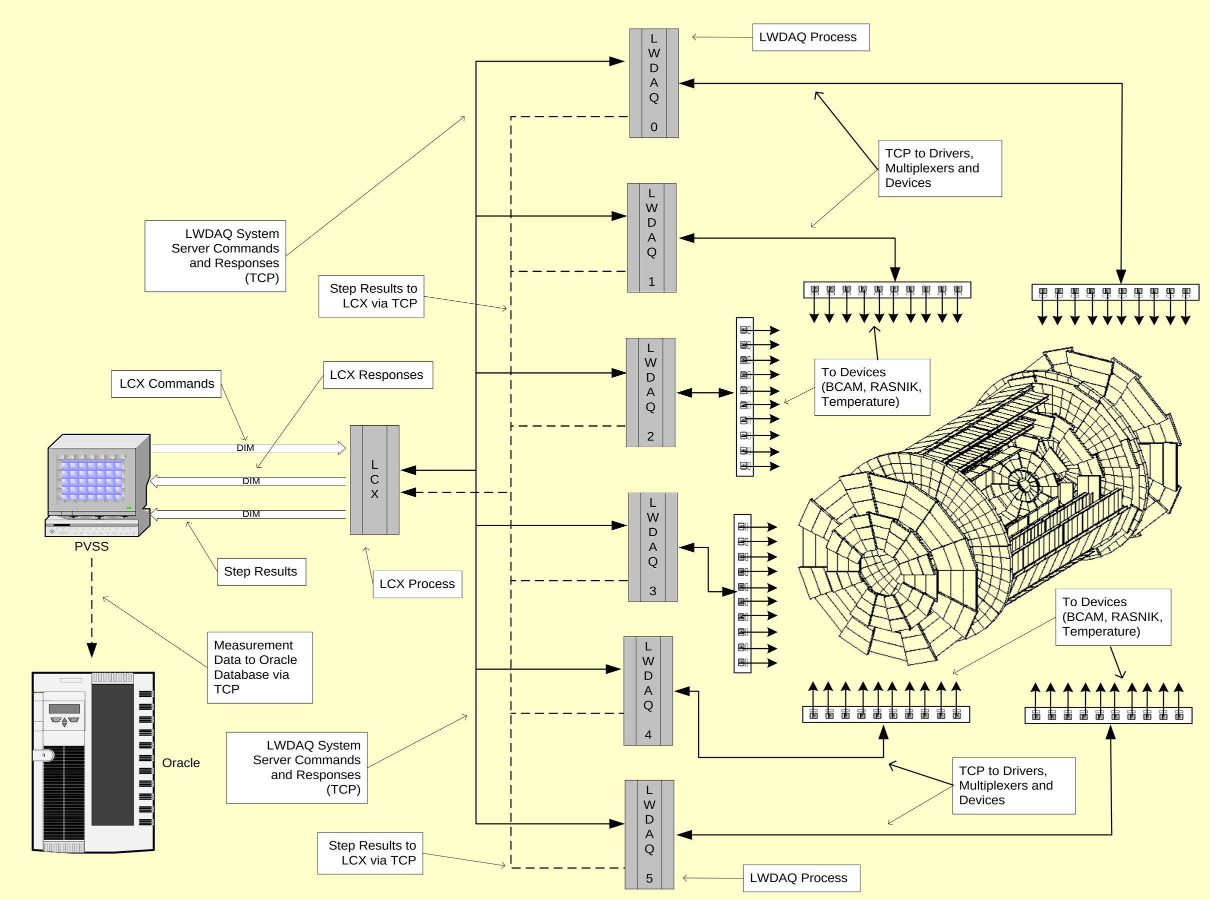
The measurement process in the six LWDAQ processes is ultimately controlled by a PVSS SCADA user interface (UI) running on a Windows machine.

The UI program talks to a control process over the CERN Distributed Information Management (DIM) protocol. This control process, called LCX, then oversees the details of managing the LWDAQ processes and relays commands and intermediate step results to and from the LWDAQ via TCP/IP.

Both the PVSS user interface and the LCX control process are designed to be extremely flexible with respect to the number of LWDAQ measurement processes.

The PVSS user interface and the LCX control process are easily extendible to accommodate additional LWDAQ processes. The LCX is dynamically configured as requests to run measurement processes are received from the PVSS user interface. Changing the number of LWDAQ processes that the UI control is done by adding a new tab in the PVSS panel interface builder.

The Control and Monitoring System



The complete system consists of the alignment bars and sensors, the LWDAQ hardware and software, a process running the LCX control program, a Windows computer running the PVSS-based User Interface, and an Oracle Database to hold the results of the measurements.

An operator uses the PVSS user interface to control the actual measurement process and can run measurement scripts in parallel continually in a loop mode for normal operation, or can load and execute diagnostic scripts to debug problems.

The status of the entire alignment system is visible at-a-glance in the user interface and the operator can watch as measurements are made and returned by the LWDAQ processes.

Offline tools are available to examine raw images from the alignment system sensors for problems. The highly contrast stretched image below-left shows that a BCAM is actually measuring the position of a reflection off of a bolt. The image to the right shows a RASNIK found with a very dusty CCD.

The Final Product

The ultimate purpose of all of this hardware and software is to gather alignment information that will be used in the offline muon track reconstruction to correct for misalignment of the Monitored Drift Tube chambers. Christoph Amelung (CERN) developed the program ARAMySS to reconstruct this alignment information from the position information recorded by the alignment system sensors.

Conceptually, the alignment system consists of a number of coordinate systems. Groups of points in a common coordinate system represent a rigid body, e.g. an alignment bar. The alignment system sensors link points in the different coordinate systems. For example, the BCAM sensors link two points with the coordinate system located at the BCAM pivot point.

The actual alignment is reconstructed by comparing measured values from sensors to a set of assumed positions and orientations and minimizing the difference by varying the assumed positions and rotations. Bar shape functions and chamber shape functions were developed to take into account the additional complexities of bodies that can mechanically deform and thermally expand.

The diagram to the right shows the results of the entire process with measurements performed by the alignment system and confirmed by a survey (graphic due to Amelung). The grey areas show the nominal positions of the MDT chambers. The black lines show the actual positions (with the displacements exaggerated). The red and green arrows show shifts of the four corner points of each chamber. Similar graphics show shifts of the corner points in the ATLAS Z direction.

The alignment system is running in the ATLAS pit. Consistent reconstruction results have been confirmed by a survey and 40 um sagitta accuracy is expected before the first collisions; and the absolute location of the encaps in the ATLAS coordinate system are known to better than 500 um.