

# Muon Barrel Alignment system based on a net of PC/104 board computers

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## Abstract

For the precise measurement of the positions of the barrel muon chambers in the CMS detector, a Position Monitoring System has been developed. It comprises ~10000 LED light-sources, 600 active pixel sensor monochrome video cameras, 24 tilt and 72 temperature sensors, 36 PC/104 board computers and a master control workstation for controlling the system and collecting and analyzing the data received from the sensors and cameras.

The aim of this paper is to present and discuss the logical organization of the system, the applied tools and methods as well as the first test results.

## I. THE BARREL MUON ALIGNMENT SYSTEM

To obtain the required muon momentum resolution in the CMS detector [1] to be built at the Large Hadron Collider (LHC) at CERN (Geneva, Switzerland) the positions of the muon detectors with respect to the central tracker must be known with the precision of the order of 100 to 400 micrometers from the inner to outer chambers respectively. This information is provided by an optical monitoring (also

called alignment) system. It consists of four parts: the tracker, barrel muon and end-cap muon internal alignment systems and the link system connecting the other three parts [2]. The muon barrel alignment system that measures the positions of all the barrel muon chambers (250 altogether) is based on a network of LED light sources, video cameras and rigid mechanical structures (Fig.1).

36 rigid structures (called MABs - Module for Alignment of the Barrel) are fixed to the iron of the return yoke of the CMS magnet and are supporting the video cameras. The muon chambers are equipped with LED light sources that are monitored by the cameras. The system also contains diagonal connections between MABs where the cameras are observing LEDs installed on other MABs, and optical distance measurements where cameras are observing LEDs installed on long bars of known distance (called z-bars).

The total number of the elements: 36 MABs, 9 to 24 cameras per MAB, ~10000 LEDs (40 per muon chamber), 6 z-bars. The system is completed by tilt-sensors (1 per MAB) measuring the orientation of the MAB with respect to the gravity and temperature sensors (2 per MAB).

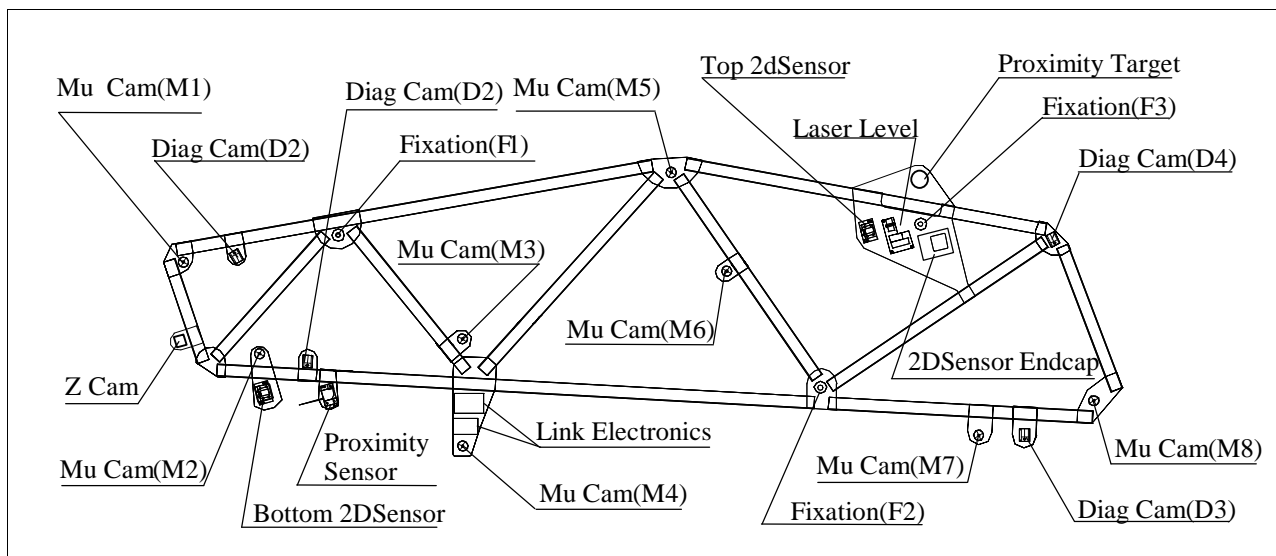


Fig. 1: Rigid structure of a Module for Alignment of the Barrel (MAB).

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## II. THE CONTROL AND DAQ SCHEME

During the operation of the system the LEDs are switched on in a predetermined sequence. The centroid (center of mass) of each light spot detected by the video cameras is calculated. Finally, the positions of the barrel muon chambers are reconstructed from the coordinates of the centroids. The full system is controlled by a SCADA (Supervisory Control and Data Acquisition) workstation located in the control room.

For local control, collection of the data from the video cameras and the sensors as well as the calculations of the centroids is performed by local computers installed at the MABs. These computers are built up as a stack of PC/104 cards and called as board computers (BC). The general scheme of the control-DAQ (Data Acquisition) system is shown in Fig.2.

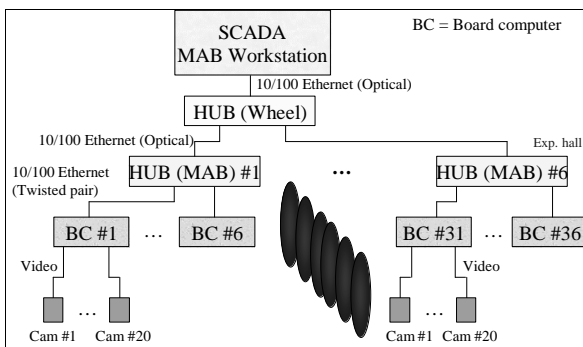


Fig. 2: Logical scheme of data acquisition and control

## III. SOFTWARE ASPECTS

The board computers have a 96-Mbyte DiskOnChip [3] each, where the operating system and the application program/data can be placed. The operating system is chosen to be a Linux system, where most of the required tasks have their supporting tools among the system facilities. These are the device drivers of the FrameLocker [4], the Ethernet interface and the DiskOnChip itself. The last one is very crucial, because without having the proper format on the DiskOnChip, the system cannot boot.

Tri-M Systems [5], that has shipped the MZ104 PC/104 configuration, provided a downloadable Linux system, which can be booted directly from the DiskOnChip. It is a heavily tailored binary system, occupying half of the 96 MByte. It is generated from Slackware 8.1 [6] with kernel version 2.4.18. No developing tools could be included in this minimum runnable system, so if someone intends to do some kernel level programming, the whole Slackware 8.1 has to be regenerated in another system including the development tools as well.

After having a developing system with the very same kernel, one can produce the needed device drivers, application programs and can install other packages like DIM [7].

DIM is a communication system for distributed / mixed environments, it provides a network transparent inter-process communication layer. It is used in different CERN experiments where several servers are making data acquisition and measurement control, and clients in several places want to

have online data and control information. The role of DIM in the client/server communication is shown in Fig.3.

In our case the board computers will be the DIM servers. In the following section the obligatory tasks of such a server are discussed.

## IV. THE TASKS OF A BOARD COMPUTER

The application program should perform the tasks below:

- read and save the pictures of the connected cameras through the FrameLocker, and to calculate the centroids of the images of the LEDs in the pictures,
- read tilt sensor data as analog input voltage,
- switch on/off z-bar LEDs and LEDs mounted on the MAB,
- publish services and available commands for the DIM name server,
- produce watchdog signals for the DIM name server.

### A. Read and save video camera pictures

Each BC has 9-24 cameras connected through a video multiplexer to the FrameLocker card. 384x287 pixels of 256 gray scales are read and stored in the RAM. Then the centroids of the white spots corresponding to the LEDs in front of the camera have to be calculated. This task seems to be a good application of the training phase of a Radial Basis Function (RBF) neural network method [8], because at the end of the training (= supplying the coordinates of all the non-black pixels) we get the center of the spots.

So far only a DOS program was used for reading through the FrameLocker, because the Linux kernel version did not contain the module for the video chip BT819/BT829 of the card. The latest kernel version on DiskOnChip now has a loadable module called BT819 to be used from the application program. The newer versions of the FrameLocker contain BT829, for which we could not find a loadable module in Slackware 8.1. A driver source code with this name was found on the web, which has to be tested.

### B. Read tilt sensor data

A special device is installed for measuring the tilting comparing to an initial state. Its data is read as analog input through the custom-built interface card of the BC. Six such sensors are fixed on the outer surface of the wheels. These data are stored as 12-bit voltage values.

### C. Switch MAB and z-bar LEDs

Unlike LEDs on the muon chambers, there are LEDs fixed on the MABs and z-bar LEDs, which has to be switched on/off, by the BC. These are TTL outputs and most probably will be put through the custom-built interface card. The commands for such a switch will come from the control workstation (DIM client).

#### D. Publish services and commands to DIM

DIM solves the regular dilemma of “polling or interrupts” for the application program. The BC has to publish the services, which are useful for the possible clients, and the clients will call the services using the interrupt exception method on the server BC. It means that the application program on the server BC has to contain the routines of the published services, but they don’t have to even know when and who activated them. The only difference between service and command is that the service can be called not only once at a time, but a time period can also be given in a call and then the service will automatically give data to the client at each end of the given time period.

#### E. Watchdog signals to the DIM name server

DIM system has a database of server and services data. It is dynamically updated by the servers using a process called DIM name server. It can run either on a server or on a client or in a separate computer. The clients read the database in order to know what services are available, how and where they can be called, which servers are active. To maintain this last data the servers has to give regular signals to the name server to confirm their availability for the clients. If such a signal is missed, the name server deletes the active flag of the server, so the clients will know it, when acquiring this type of information from the name server. Fig. 3 shows the data flow between the main DIM components.

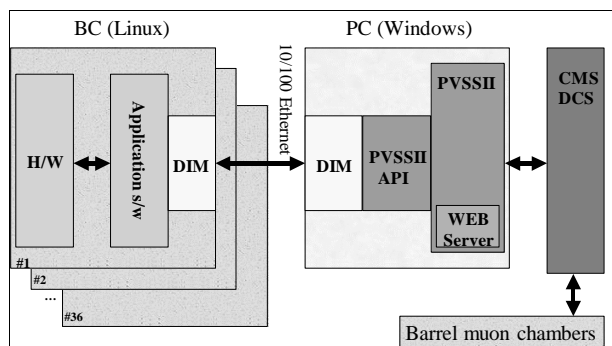


Fig. 3: Logical connections through PVSS II.

#### V. PROCESS CONTROL AND VISUALIZATION

For controlling the processes and visualize the actual state of the system PVSS II [9] of ETM will be applied. It is an industry-independent, universal control system for the visualization, monitoring and control of technical processes. PVSSII has its own, device oriented programming language, Control, that can be situated somewhere between C and C++. It has to our experiences proven to be an intuitively easy to use program, even for people with little programming experience. Our simulation tests on a PC with NT operating system show that it is enough flexible and scalable to meet our requirements. The logical connections between the SCADA workstation and the BCs and with the CMS Detector Control System (DCS) are shown in fig.3.

#### VI. HARDWARE TESTS

Because of the BC will be placed on the CMS Muon Barrel, it has to withstand both radiation and magnetic field.

The MZ104 PC/104 Board Computer was irradiated by 95 MeV protons at the cyclotron of the Svedberg Laboratory [10] in Uppsala, Sweden. During irradiation the computer regularly grabbed the video signal of a camera and saved the pictures to its DiskOnChip flash memory. The Ethernet connection is a crucial part of the final application so it was also monitored by regular network traffic.

During the irradiation two different proton rates were used:  $4 \cdot 10^7$  and  $1.5 \cdot 10^8$  protons/cm<sup>2</sup>/sec. At the higher rate some errors were found like the saving of the pictures stopped, or the computer hung and had to be restarted. At the lower rate there was no failure. The total number of protons ( $2.5 \cdot 10^{10}$  protons/cm<sup>2</sup>) corresponds to 4-times the LHC lifetime (25% of which was the row rate part) and there was no permanent failure

Magnetic test was also performed. The magnetic field, which has to be tolerated by the device, is 2T. During the test a static magnetic field with increasing strength was applied to the board computer. Two malfunctions were found; the Ethernet communication stopped working above 0.4T and at a bit higher magnetic field the processor stopped working, too. The origin of the problem in the Ethernet circuitry was identified to be the isolation transformer. The solution of the problem was to remove this component from the board and replace it with short-circuits. This can be accepted as the planned network is a dedicated one and the other end of the Ethernet cable will be isolated. The reason for the halting of the processor found to be a ferrite core in a DC-DC converter on the motherboard of the computer. Further effort has to be made to eliminate this problem.

#### VII. SUMMARY

The present status of the development of the muon barrel alignment system was discussed. Mainly the logical organization, the distribution of the tasks and the communication between the intelligent parts were presented. Our experiences with the first examples of the would-be components served as benchmarks, which could substantiate the final procurements.

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