Online data acquisition and the control system for the Double Chooz experiment

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Abstract. The Double Chooz experiment searches for the neutrino mixing angle $\theta_{13}$ using two identical detectors and reactor neutrinos. Each detector is composed of three sub-detectors, and each sub-detector has 390, 78, and approximately 3000 channels. In order to acquire pulse shapes of photomultipliers, the two kinds of Flash-ADC are used for two sub-detectors. Although the trigger rate from the physics process is not high, an event size is about 1 MB per event due to FADC readout and is not small. The data acquisition has to be controlled outside the neutrino laboratory site, because the detector is located in a nuclear power station, and access to the laboratory is restricted. For these reasons, we need deadtime free DAQs and trigger systems, with a low energy threshold, and the remote control and monitoring systems for all online processes. This paper presents the online data acquisition and the control systems for the Double Chooz experiment.

1. Introduction
The Double Chooz experiment aims to measure the unknown neutrino mixing angle $\theta_{13}$ using reactor neutrinos [1], and is currently commissioning the dedicated detector and online systems, to start physics data taking in the beginning of 2011. We have two identical detectors, called near and far detector, for cancellation of many systematic uncertainties which come from neutrino flux, by comparing the measurements from two detectors. The detectors are placed at about 400 m from the reactor core for the near detector, and 1.05 km for the far detector.

The Double Chooz detector [2] consists of four concentric cylindrical tanks and several layers of plastic scintillator strip detector. From innermost volume, there are two kinds of liquid scintillator and mineral oil layers called 'target', 'gamma-catcher', and 'buffer', separated by acrylic vessels. In the buffer tank, 390 low background 10-inch photomultipliers (PMTs), Hamamatsu R7081MODASSY [3], are put on the stainless steel vessel for 13 % photocathode coverage. The next volume called 'inner veto (IV)' is a 50 cm thick liquid scintillator volume contained in a steel vessel. It is optically separated from the other regions and holds 78 8-inch PMTs, Hamamatsu R1408 [3]. On top of the main detector, there is an active tracking detector made of plastic scintillator strips with wavelength shifting fibers and multi-anode PMTs, called 'outer-veto', to reconstruct cosmic-ray muons.

The detection of anti-electron neutrinos is via inverse beta decay, $\bar{\nu}_e + p \rightarrow e^+ + n$, which gives a good neutrino identification method known as 'delayed coincidence'. In this method, two correlated signals for positron and neutron are identified as a neutrino event, and the backgrounds can be reduced significantly.
For data acquisition (DAQ) systems, we need deadtime-free DAQs from a low energy threshold in order to ignore systematic uncertainties from deadtime. Although physics analysis is based on delayed coincidence, DAQs are running independently with single triggers, with time stamps of clock signals for offline coincidence. Hence the deadtime may affect the number of neutrino candidates and introduce the systematic uncertainties. The trigger rate is not high with respect to high energy accelerator experiments, but we acquire pulse shapes of each PMT by FADC readout and an event size becomes to be 1 MB per event. This huge data size may cause deadtime, however, it will give us a possibility of pulse shape discrimination analysis. Moreover, the neutrino laboratory is not designed as a working area, and stays inside a nuclear power station. As a result, we must control and monitor all systems from outside remotely, we needed to develop remote control system for these reasons.

In this paper, the detector readout, data acquisition, the control and the monitoring system for the Double Chooz experiment are presented.

2. Readout system

The schematic view of the readout for the buffer and IV PMTs is shown in figure 1. Each PMT has a 22 m single cable used for both signal and HV, thus the signal is separated by a custom made HV splitter. On the HV side, the voltage is set individually to give a gain of $10^7$ delivering single photoelectron pulses of approximately 10 mV, while the HV splitter outputs signals to a custom front-end electronics (FEE) after a cable of 18 m. Then FEE outputs analog signals for FADCs, and a stretcher signal to the trigger system. In Double Chooz, two kinds of FADC will work for small signals from neutrino-like events and for large signals from cosmic-rays, hence these two FADCs are called $\nu$-FADC and $\mu$-FADC, respectively. The $\nu$-FADC cards are CAEN-V1721 [4], sampling at 500 MHz and holding a buffer of up to 4 $\mu$s per trigger per channel, co-developed by CAEN and the APC laboratory. The system is expected to work dead-timeless for the expected rate of approximately 300 Hz, and all data are collected by NuDAQ described in section 3.

![Figure 1. The schematic view of the Double Chooz readout system for buffer and IV PMTs. Green and orange arrows represent analogue and digital pulses, respectively.](image_url)

In addition, the outer-veto readout system uses the Hamamatsu M64 multi-pixel PMTs in combination with the MAROC2 chip [5]. A custom electronics was developed on which each MAROC2 chip is mounted and read out via USB, then the data are collected by OVDAQ which works independently from NuDAQ.

3. Data Acquisition and Run Control

Double Chooz has two independent DAQs, NuDAQ and OVDAQ. NuDAQ consists of six Read-Out Processors called ROP, and an Event Builder Processor (EBP). Each ROP is running on VME controller in each crate, collects FADC data in its crate, and sends those to EBP on 10
Gbps local area network. The EBP is a multi-thread program to communicate with each ROP for data collection and with other systems, such as run control and online monitor, by TCP sockets. In NuDAQ, only EBP can communicate with other system, and write data to the disk storage. In Double Chooz, both ROP and EBP are developed with Ada, which is object-oriented high-level programming language, on Debian/GNU Linux (Lenny). The event size by all channels is approximately 1 MB per trigger in maximum time window of 4 μs, at 500 MHz sampling. The time window can be changed by a configuration file, and reasonable window size is re-defined for high rate runs, such as calibration runs.

NuDAQ and OVDAQ are working independently, thus they are synchronised and controlled by a common Run Control system (RC). RC consists of two systems, RC server written in C++ and RC-GUI developed with Java. Figure 2 shows DAQ states used by each DAQ and a screenshot of RC-GUI. DAQs and RC have four stable states (terminated by _S), and 5 metastates and 2 hardware states (terminated by _MS or _HS). RC server does not only synchronise each state of DAQs, but also manage the run configuration including run number and data taking time. All run information are stored in MySQL database [6], and used for offline analyses. RC-GUI for the shifter can control RC system, determine run configuration, change DAQ states by pushing the button. RC-GUI also has the sequential mode which repeats to change DAQ states automatically and enables to take data by reserved configurations.

![Image of DAQ states and RC-GUI](image)

**Figure 2.** DAQ states (left) and the Graphical User Interface of Run Control (right). There are 4 stable and 7 intermediating states.

Data taken by each DAQ are written on hard disks as binary files. Subsequently, the event processor reads data from hard disks and merges data from several DAQs into one event using clock information and to convert from binary to ROOT-tree format used in offline analyses. On event processing, taken events also input to a high level of monitoring stage, where event shapes
after event reconstruction can be shown. This monitoring is called "Pseudo-Online-Monitoring", running on the same monitoring framework as online data monitor as described in section 4.1.

When the event processing of a run is finished, either binary files or ROOT tree files are transferred to the CC/IN2P3 computing center (Lyon) [7]. The transfer status and place of all files are traced by the dedicated transfer system developed with Python, using MySQL database. Data stream from online system to the CC/IN2P3 computing center is shown in figure 3.

**Figure 3.** Data stream from online systems to the CC/IN2P3 computing center. Binary files taken by DAQ are also sent to the computing center, and information stored in MySQL database are replicated to the computing center for offline analyses.

### 4. Monitoring system

The monitoring system in Double Chooz has very important roles for the remote control, and enables to watch the system status from outside the experimental site. It is mandatory to control online systems remotely. The monitoring system may help to identify any problems of online systems and the quality of data taken by DAQ as soon as possible.

The monitoring has two purposes. One is data monitoring to check DAQ rate, data quality processed by event processor, HV and electronics status from HV control or slow control systems. All systems use a same developed framework, hence the shifter can check all data in one framework. Another purpose is to know the online processes and system status. Double Chooz prepared two different systems, and complementary to the data monitoring system.

#### 4.1. Data Monitoring

The monitoring framework for online data is prepared and consists of three parts, DAQ subsystems, 'Monitor Server', and 'Monitor Viewer': TCP connects each part of the system. The DAQ subsystems, such as each DAQ, slow control and the event processor, create and send histogram collections named 'Histogram packages'. Then Monitor Server written in C++ stores them in shared memories to allow for different performances between Monitor Server and Viewer, and sends information to Monitor Viewers.

We use two platform independent technologies to implement the Monitor Viewer: Java and Google Web Toolkit [8]. They behave the same to collect data, such as bin contents of histograms, from the Monitor Server via the network, and to make graphical plots on their windows by themselves. Monitor viewers are free from any libraries or plugins, like ROOT [9], and have been tested on several popular operating systems. The GUI layout can be controlled by XML.
based files, and information to create plots is provided by Monitor Server. Figure 4 shows screen shots of online monitor GUI at the detector commissioning.

The detailed description of data monitoring framework is given in [10, 11].

4.2. Process Monitoring

Three monitoring systems for processes are available in Double Chooz online framework. These systems consist of an ‘Alert system’ to deliver notifications from each online system, a ‘Log Message system’ to manage all log messages, and a ‘Remote Process Control system’ to monitor processes running on other machines and to allow the user to control/restart them. The role of these systems is to provide all the information corresponding to the status of the online systems, to shifters and experts via network. A Java GUI, accessible from outside, displays the accumulated information.

Alert system’s purpose is to deliver notifications from each online process to shifters and experts, using a pop-up window. This system is running independently from any other systems in the Double Chooz online framework. All online processes use a common interface in order to send notifications to the Alert system. The system consists of two processes, Alert server and the viewer. The Alert server is the main process of this system and an overview is shown in figure 5. The server implemented in C++ has two kinds of threads for each online process and viewer GUI, respectively. When an online process tries to connect to the server, a receiver thread is instanciated in the server. The receiver thread receives messages from the online process and put it into a queue in the deliverer thread. At the same time, the deliverer thread gets the message from the queue of messages, and send to all GUI viewers sequentially. Then, a pop-up window appears on the viewer side. The alert system is able to notify the shifters about the status of the system reliably and as soon as possible.

The Log Message system is responsible for all log messages generated by each process. As shown in figure 6, the system collects and shows log messages using syslogd. A syslogd in a machine receives local log messages from processes via a system call, then sends to a remote syslogd. Since syslogd can also pass these messages to other processes via a FIFO called pipe, the Log Message server which is the main part of the system can receive all messages from all online processes. The data processing in Log Message server is similar to Alert server, and messages are sent to all viewer GUIs using TCP. The viewer GUI stores and shows messages sequentially on the window. Moreover, the viewer can filter messages by priority dynamically.

Figure 4. Screen shots of online monitor GUI. The left figure is the run state monitor, and the right is HV monitor.
5. Conclusion

The Double Chooz experiment is a neutrino oscillation experiment that will measure the undetermined mixing angle $\theta_{13}$ or improve the current best limit, using reactor neutrinos at the Chooz nuclear power plant in France.

Since the neutrino laboratory is not designed as a working area for us, we have to control and monitor all systems from outside. For data acquisition system, although the trigger rate is not high with respect to high energy collider experiments, an event size of about 1 MB per event is large due to FADC readout. Therefore, the dedicated systems are developed to suit the access constraint and to handle large data size.

Currently, the full detector commissioning with all online systems has been well ongoing since summer 2010, and the physics data taking will start in the beginning of 2011.

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