A Data Quality Monitor System for the NESTOR Experiment

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Abstract

In this note we describe the Data Quality Monitor system for the NESTOR experiment. The system consists of several PC-nodes connected directly to the Data Storage System, inspecting continuously the accumulated data. The system is fully automated providing a detail overview of the operational, environmental and experimental status of the detector.

1. Introduction

The NESTOR detector [1,2] deployed in March of 2003 was a fully equipped NESTOR floor along with many environmental systems attached to the sea bottom station.

Figure 1

*The NESTOR floor during deployment at the Navarino gulf at Pylos. At the tips of the arms there is one pair of photo multiplier tubes one looking upwards and the other looking downwards*
A NESTOR floor consists of 6 pairs of Photo Multiplier Tubes (PMTs) [3], placed around a large titanium sphere which houses the floor electronics. The PMTs in each pair are arranged in such way that one is looking upwards (towards zenith) and the other is looking downwards (towards nadir) (Figure 1). The bottom station, which plays the role of the anchor of the NESTOR floor, is equipped with many environmental sensors like pressure meters, acceleration meters, water current meters etc.

When a muon passes near the detector volume, the emitted Cherenkov light is collected by the PMTs, and the floor electronics board digitizes the produced electrical pulses. If certain criteria are fulfilled (trigger condition), the digitized waveforms along with the environmental data are transmitted to the Shore Laboratory where the raw data are recorded [4].

The Data Acquisition System at the Shore laboratory of the NESTOR Experiment is constituted of a cluster of PCs having dedicated CPUs to different tasks [5]. It can be divided in 4 different subsystems (Figure 2):

- The Floor Communication system, which is responsible for the communication with the floor electronics inside the titanium sphere,
- The Data Storage system, which is responsible for data storing to recording media,
- The Online Monitor system, which represents graphically the environmental and operational conditions of the detector [6], and
- The Data Quality Monitor system, which is responsible for checking the quality of the accumulated data.

All the computers of the DAQ cluster are interconnected via a Fast Ethernet link while one of the computers has access to the Internet via a modem connection. All the computers are synchronized to GPS time and equipped with UPS for safety in case of power breakdown.
2. The Data Quality Monitor System

The Data Quality Monitor system consists of a cluster of PCs running under the Linux operating system. The system executes a software package written in Fortran, Shell Scripting Language and Paw\(^1\) scripts. It receives the latest data files from the Data Storage system, and after processing the raw data it performs a fast analysis of the PMT signals and updates a local database of RZ-files\(^2\). The database contains all the environmental, operational and experimental parameters of the detector as well as the result of the signal processing procedures. The program can be executed in many instances allowing many users to examine the data simultaneously.

In particular the Data Quality monitor supplies information concerning:

1. The operational characteristics of the PMTs.
2. The status of the environmental conditions.

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\(^1\) PAW (Physics Analysis Workstation) is a software package developed at CERN for High Energy Physics data analysis

\(^2\) Database format used widely in High Energy Physics
3. The performance of the Trigger system.
4. The performance of the Floor Communication system.
5. The performance of the PMT pulse digitization procedure.
6. The overall tracking capability of the detector

2.1 Operational characteristics of the PMTs

The Data Quality Monitor System examines the proper operation of the photomultiplier tubes by checking the stability\(^3\) of:

- The pulse height distribution of each PMT,
- The counting rate of the PMTs, and
- The distribution of the total number of photoelectrons inside the trigger time window.

The pulse height distribution depends on the operational characteristics of the PMT and must not change during a run. At the beginning of a run the pulse height distribution is recorded and then each data file is checked in order to detect any deviations that would indicate a change on the operational characteristics of the detector (Figure 3a).

Furthermore, the counting rate of a PMT should remain stable as long as the operating high voltage and the PMT threshold value do not change (Figure 3b). The counting rate per PMT during the 2003 Run was measured to be about 50 kHz per PMT, where the main contribution came from the thermionic noise and Cherenkov light produced from decays of K\(^{40}\) [7]. Large deviations are acceptable in case of bioluminescence activity\(^4\), which occurs for 1\% of the experimental time.

In addition to the pulse height distribution, the pulse height in units of the mean of the single photoelectron distribution (referred simply as photoelectrons) can be used as a crosscheck of the PMT characteristics. The total number of photoelectrons inside the experimental trigger time window\(^5\) should be constant during the run (Figure 3c). Deviations from the standard shape obtained at the beginning of a run would indicate that something has changed or that a new calibration procedure must be deployed.

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\(^3\) Under constant experimental conditions
\(^4\) Living organisms that emit bursts of light.
\(^5\) The trigger time window is determined by the time that the light needs to cover a distance equal to the diameter of the Nestor floor.
2.2 The monitoring of the detector status.

The detector status and the environmental conditions are continuously monitored by checking:

- The high voltage of the PMTs,
- The high voltage supply of the system,
- The temperature inside the titanium sphere,
- The hygrometer values.

![Diagram showing various environmental parameters](image)

**Figure 4**

Some of the environmental parameters examined by the Data Quality Monitor system during the period of accumulation of one data file (2613 events). a) The high voltage of a PMT. b) The power supply voltage, c) the thermometer values and d) the relative humidity inside the titanium sphere.

The High Voltage applied to the PMTs is continuously monitored since it affects the operation of the PMTs and consequently the performance of the whole system (Figure 4a). On the other hand, the main power supply to the system is checked in order to ensure that it is above a threshold value (of about 250 V) (Figure 4b), while 6 temperature sensors at various locations inside the titanium sphere, provide crucial
information about the operation of the electronics\(^6\) (Figure 4c). Finally, any leak on the titanium sphere will be detected by an enhancement of the relative humidity, which is monitored by the four sensors placed inside the sphere (Figure 4d).

2.3 The performance of the Trigger system.

The performance of the Trigger system is evaluated by examining:

- The trigger signal which is digitized along with the PMT waveforms,
- The stability of the trigger rate,
- The stability of the majority counting rates,
- The dependence of the total number of photoelectrons inside the trigger time window on the coincidence level.

The floor electronics board contains five 4-channel ATWDs, which digitize the PMT signals, the clock waveform and the trigger logic signal. The trigger logic signal is digitised in order to estimate the time of occurrence of the trigger. As a reference point we chose the inflection point of the trigger signal (inner plot of Figure 5a). Under normal operation conditions the time of occurrence of the inflection point should remain constant. In other words the ADC channel, which corresponds to that time, must be the same. In Figure 5a is shown this ADC channel during a run.

In addition the trigger rate as well as the majority counting rates should be stable during a run (Figure 5b, 5c). A deviation would indicate that something is going wrong either to the trigger formation or to the PMT characteristics (i.e. the threshold values or the high voltage have been altered).

Finally, the distribution of the total number of photoelectrons inside the trigger time window with respect to the coincidence level is a good estimator of both the selection trigger and the PMT detection efficiency. It is obvious that the coincidence level and the total number of collected photoelectrons are correlated (Figure 5d) and this correlation must not change under the same experimental conditions.

\(^6\) Many operational parameters like the sampling period of the ATWDs are affected by a substantial increase of the temperature at the Floor board.
The trigger performance examined by the Quality Monitor system. The data were accumulated with a four fold coincidence trigger logic. a) The timing of the inflection point of the trigger signal (insert plot) remains stable, b) the trigger rate is constant, c) the 2-fold majority rate (upper plot) and the 3-fold majority rate (lower plot) as a function of time, and d) the distribution of the total number of photoelectrons inside the time window (solid points) compared with the standard distribution obtained at the beginning of the run (histogram).

Measuring the distribution of the time interval between two subsequent events can provide another test for the stability of the trigger rate. This distribution should follow an exponential distribution:

\[ p(t) = Ce^{-\lambda t} \]

where the parameter \( \lambda \) is the trigger rate during the run.
In Figure 6 it is shown the time difference distribution along with the exponential function that fits the data. The estimated parameter $\lambda$ is $3.55 \pm 0.08$ which agrees with the mean trigger rate during this run ($3.50 \pm 0.07$ Hz).

2.4 The performance of the Data Acquisition system.

When a trigger occurs, the digitized data along with any other environmental or operational parameters are transmitted to the shore station by the Floor electronics board. The data bits are transformed to light pulses which travel via the optical fibers to the receiver of the Floor Communication system. Each event packet transmitted from the Floorboard, is received from the Shore board, which formats the event according to the raw data protocol. The Data Quality Monitor analyzes each raw data file (containing 2613 subsequent events) in order to check:

- The formation of the data.
- The existence of corrupted events.
- The dead time of the system.

In particular, each of the five ATWDs of the Floor Board has four channels each giving 128 10-bit samples of the respective digitized pulses. These 10-bit words are sifted to the left to form ($5 \times 4 \times 128 = 2560$) 16-bit words. The six Less Significant Bits (LSB) of these words, are used to carry other information. The first two bits are check bits that prove the correctness of the received data and point out the beginning of each
data packet and data block. The sixth bit is used to load the environmental data, the counter values (2, 3 and 4-fold trigger counters, event counter, PMT counter) and information about the status of the electronic boards.

In addition the system detects the periods of bioluminescence activity by checking the counting rates of the PMTs. When the counting rates of more than three PMTs exceed significantly the mean rates measured during the run, then the event is characterized as a “bioluminescence” event. The contribution of bioluminescence activity to the total experimental time was estimated to be about 1.1 % [7] (Figure 7a). On the other hand the percentage of the corrupted events during a typical run is about 0.2-0.3 % (Figure 7b). Consequently the dead time of the system is due mainly to the bioluminescence activity and is shown in Figure 7c.

![Figure 7](image)

The existence of corrupted events and bioluminescence activity contribute to the dead time of the system. The Data Quality monitor represents graphically the percentage of bioluminescence activity (a), the percentage of wrong events (b) and the total dead time of the system (c).
2.5 The performance of the digitization procedure.

The standard signal processing procedures of the Data Quality Monitor system transform the digitized data to PMT pulses and after that, further processing is applied concerning the subtraction of the electronic noise, the treatments of the overflow and overlapping pulses and the correction due to the pulse attenuation in the signal cables and electronic components.

The transformation of the digitized data to PMT pulses uses:
- The gain (ADC counts/mV) of the ATWDs,
- The ATWD sampling rate,
- The pedestals of the ATWD channels

Figure 8

The Data Quality monitor examines the gain of the 12 ATWDs (a), the sampling rate of each ATWD (b), and the pedestals of all the ADC channels of each ATWD (c).
The Data Quality Monitor checks the stability of the sampling interval during the runs (Figure 8b) whiles the gain and the pedestals of the ADCs can be estimated during electronic calibration runs (Figure 8a, 8c).

2.6 The overall tracking capability

Finally the Data Quality monitor can perform a fast estimation of the track parameters. Specifically, the digitized waveforms are processed according to the standard processing algorithms [8] and they are presented at each step graphically. For example in Figure 9 is shown the output of the signal processing procedures. The digitized data after the pedestal subtraction (Figure 9a) are transformed to PMT pulses using the gain and the sampling time interval of the ATWDs (Figure 9b). Then the response function of the electronics is taken into account in order to restore the original shape of the pulse (Figure 9c).

The final waveforms are then fitted according to the standard fitting procedure [9] in order to ensure that the reconstruction efficiency in every data file dos not deviate from the expected value.\footnote{The reconstruction efficiency of events with 6 hits inside the trigger window is about 18%.}
The Data Quality Monitor represents graphically the digitized waveforms and the result of the standard waveform analysis. For example, in this figure is shown the digitized waveform after the offset subtraction (a), after the use of the gain and the sampling rate of the ATWDs (b) and after taking into account the response function of the electronic circuits (c).

3. Conclusions

The Data Quality Monitor of the NESTOR experiment is one of the four subsystems of the Data Acquisition system at the shore laboratory. It uses the recently accumulated raw data files, applies the standard signal processing procedures to the digitised waveforms and produces many quality plots concerning the environmental and operational condition of the detector. Special attention is given to the performance of the trigger system, the digitisation procedure and the tracking capability of the detector.
Finally, the Data Quality monitor updates a local database of RZ-files that is used by the Offline Analysis software

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References

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