Slow monitoring system for the JSNS$^2$ experiment

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Abstract: The JSNS$^2$ (J-PARC Sterile Neutrino Search at J-PARC Spallation Neutron Source) experiment is designed to look for neutrino oscillations over a 24 m short baseline at J-PARC. The JSNS$^2$ inner detector is filled with 17 tons of gadolinium(Gd)-doped liquid scintillator (LS) with an additional 31 tons of un-doped LS in the optically separated $\gamma$-catcher and outer veto volumes. A total of 120 photomultiplier tubes detect the scintillation event. Additionally, two anti oil-leak protection walls surround the detector to prevent leakage of the LS outside of the detector in any case. While filling the Gd doped LS and the un-doped LS, it is important to match the liquid level in the different layers to reduce stress between the layers. And it is also important to monitor inside of the anti oil-leak protection wall to confirm there is no leakage. For this purpose, we prepared ultrasonic level meters, temperature sensors, pressure meters, a flow meter. We adopted the LabVIEW program to acquire the sensor values and to record them in the MySQL database. We connected the database to the Grafana graphic tool. It is convenient to set the threshold values for warning and to draw the history of each sensor. All the combined systems are prepared and the demonstration shows promising performance for the JSNS$^2$ experiment.

Keywords: Detector control systems (detector and experiment monitoring and slow-control systems, architecture, hardware, algorithms, databases), Neutrino detectors
1 Introduction

The JSNS \(^2\) (J-PARC Sterile Neutrino Search at J-PARC Spallation Neutron Source) experiment aims to search for short baseline neutrino oscillation with \(\Delta m^2\) near \(1\ eV^2\) at J-PARC \([1]\). The detector consists of an inner target filled with 17 tons of gadolinium(Gd)-doped liquid scintillator (LS), an optically separated intermediate \(\gamma\)-catcher and an outer veto filled with 31 tons of un-doped LS \([2, 3]\). A total of 120 10-inch photomultiplier tubes (PMTs) observe the optical photons from the scintillation event. Two anti oil-leak protection walls surround the detector to prevent any leakage of the LS. While filling both the Gd-doped LS and un-doped LS, the liquid level should be balanced within a tolerance, which is not set in the body, however, within 15 cm in the chimney. Four ultrasonic sensors are prepared to monitor both the filling status and the normal operation, and a flow meter is prepared to monitor the speed of filling. The detector will be air-tightened, therefore there could exist pressure difference between the detector and the atmospheric pressure. Two relative pressure meters are prepared to measure the difference. If the temperature increases, the volume of both the Gd-doped LS and un-doped LS will expands due to the thermal expansion. Eight PT-100 thermocouples (RTDs) are installed in the veto layer to monitor the temperature. Additionally, four ultrasonic sensors monitor inside of the first anti oil-leak protection wall to confirm there is no leakage from the detector. One high voltage (HV) crate with six power supplies...
delivers preset voltage to each PMT. To read values from the various sensors and to control the HV system, we adopted the LabVIEW program. It is connected with the MySQL database to store each value periodically. The Grafana graphic tool is selected to monitor the tendency of each sensor value according to the different time range. Furthermore, the Grafana can set threshold with a combination of the database to generate an alarm for the emergency. In this paper, we present the detail of each sensor and the HV system in section 2, the LabVIEW and the database in section 3, and the Grafana in section 4.

2 Sensors and High Voltage

In this section, we describe the detail of each sensor. Table 1 shows the sensors including a model number or a manufacturer and Fig. 1 shows the installed position of each sensor with the JSNS² detector.

| Name (Type)               | Purpose (location) | Analog output (port) |
|---------------------------|--------------------|----------------------|
| Ultrasonic (SICK, long range) | Filling and Extracting | Voltage |
| Ultrasonic (SICK, short range) | Normal operation | Voltage |
| Ultrasonic (Arduino)      | Anti oil-leak protection wall | USB |
| Ultrasonic (Arduino)      | Level stabilizer tanks | USB |
| Temperature (RTD)         | Temperature of the LS | NI 9216 (*) |
| Ambient monitor (TR73-U)  | Experimental hall | RS232 to USB |
| Pressure meters (GC-31, GC-62) | Relative pressure | Voltage |
| Flow meter                | Filling and Extracting | Current |
| Web camera                | Anti oil-leak protection wall |

Table 1: Summary table of each sensor with the purpose. (*) RTDs are connected to the National Instrument (NI) 9216 module which is a commercial module for the RTDs. We chose an NI 9201 module for the voltage output sensors and an NI 9203 module for the current output sensors. The NI cDAQ-9178 Crate houses all of the NI modules and connected to the Slow Control and Monitor system (SCM) PC with a Universal Serial Bus (USB). All other sensors are connected to the SCM PC via USB serial port except web camera.

2.1 Ultrasonic level meters for the filling and the normal operation

We adopted the ultrasonic level meter from the SICK company [4] which has two main purposes. One is to be balanced the height of the Gd doped LS in the target with the un-doped LS in the γ-catcher and the veto while filling, and the other is to monitor them during the normal operation. Due to the limitation of the detection range, we decided to use two different ranges of the ultrasonic level meters. The long-range level meter, SICK UM30-215113 [5], can measure the distance between 600 mm to 6000 mm, and the short-range level meter, SICK UM30-213113 [6], can measure the distance between 200 mm to 1300 mm. The long-range level meter is dedicated to the Gd-doped LS and the un-doped LS filling, and the short-range level meter is dedicated to the normal operation. We installed a pair of both the long-range and the short-range sensors on the detector chimney and on the flange of the veto region. Figure 2 shows a photo of both ultrasonic level meters. The level
Figure 1: Installed position of each sensor with the JSNS$^2$ detector.

The meter displays the distance on the LED and generates voltage output (0 - 10 V) which is proportional to the distance between the liquid surface and the level meter.

Figure 2: A photo of the ultrasonic level meters.

2.2 Arduino system for the anti oil-leak protection wall

We decided to install four ultrasonic level meters to monitor inside of the first anti oil-leak protection wall and two ultrasonic level meters on the level stabilizer tanks. The level stabilizer tanks, which are not within the scope of this paper, physically expands the surface area of the chimney to manage the thermal expansion of the Gd doped LS. The region of interest is between 50 mm to 300 mm.
which is not proper with the SICK short-range sensor. Therefore, we prepared another ultrasonic level sensor, US-015 [7], which can measure the distance between 2 cm and 400 cm and has a resolution higher than 1 mm. US-015 is connected to Arduino Uno Rev3 [8] which is a one-board microcomputer. Arduino Uno Rev3 is connected to a PC with a 10 m USB cable. Arduino reads out the measured distance from the US-015 as a digital number and sends it to the PC via RS-232-C serial communication, while sends it to the 0.96 inches OLED display module including SSD1306 single-chip CMOS driver [9], produced by SUNHOKEY Electronics Co. Ltd., via I2C serial communication to check the distance without any PC. Figure 3 shows a diagram of the module and the pictures. The US-015 sensor is installed downward in the module and measures a distance to the liquid level in the level stabilizer tank or floor in the anti oil-leak protection wall to check whether the distance is shortened due to the oil-leakage or not.

![Figure 3: It shows line connections between the Arduino (left-bottom), the US-015 ultrasonic sensor (top-left) and the OLED display module (top-middle). The right-top shows the encapsulated box which houses the Arduino system. The distance on the OLED display is shown through the hole. The right-bottom shows the installation status.](image)

### 2.3 PT-100 thermocouples

If the temperature increases more than 36 degrees, the level stabilizer tanks can not manage the thermal expansion of the Gd doped LS. Therefore, it is required to monitor the temperature from the safety to prevent the liquid overflow. We prepared 8 RTDs to measure the temperature of the LS in
the detector. 4 RTDs are installed at the bottom of the veto layer and the other 4 RTDs are installed at the middle position of the barrel of the veto layer with 90 degrees apart from each sensor. The analog output can be read with an NI 9216 module.

2.4 Flow meter and inverter

We prepared a flow meter, FM3104-PD-XP/K [10], to monitor the flow rate of the LS at the stage of filling. Because the flow rate is correlated with the electric frequency, to control the filling flow rate, we installed an inverter to the pump. The flow meter displays the flow rate on the LED and generates current output (4 - 20 mA) which is proportional to the flow rate.

2.5 Pressure meters

JSNS detector will be air-tightened to prevent oxygen contamination in the Gd doped LS and the un-doped LS. It could generate a pressure difference between the detector and the atmosphere, which can apply external force to the detector. The detector vessel is strong enough for the positive pressure (up to 20 kPa [3]), however, weak for the negative pressure. For the safety, we prepared two different relative pressure meters, GC-31(±100 kPa) [11] and GC-62(±2 kPa) [12]. The GC-62 measures the pressure difference between the detector chimney and the veto layer. The GC-31 measures the pressure difference between the inside of the detector and the atmospheric pressure. If the relative pressure difference is larger than the warning level (for example due to the typhoon), we will break air-tight to reduce the pressure difference for safety. Each sensor provides voltage output (1 - 5 V) which is proportional to the pressure difference. If there is no pressure difference, then it generates 3 V. More than 3 V indicates there exist positive pressure difference and vice versa.

2.6 TR73-U

We prepared one portable ambient sensor, TR-73U, to monitor the temperature, the humidity, and the atmospheric pressure at once. Each value displays on the LCD panel. We can read each value, not the analog output, via RS232 connector to the PC. Note that we converted the RS232 to the USB for the convenience.

2.7 High Voltage

The CAEN SY1527LC crate with six A1535 modules [13], which were used for the Double Chooz experiment, are reused to supply high voltage to each PMT. One CAEN A1535 module can supply 24 different high voltages (HV) up to 3.5 kV. The CAEN OLE (Object Linking and Embedding) for Process Control (OPC) server can communicate with the crate and the modules to call the available parameters. For the JSNS experiment, we call the temperature of each A1535 module, supplied voltage of each channel, and current of each channel.

3 LabVIEW interface

3.1 Slow Control and Monitor system

We adopted the LabVIEW system to read and save the sensor values, except for the web cameras, with a SCM PC with Windows 10. NI modules are widely used with the LabVIEW system. We
prepared one NI 9216 module for the RTDs, one NI 9201 module for the analog voltage output, and one NI 9203 module for the analog current output. The NI cDAQ-9178 Crate houses three NI modules and connected with the SCM via USB cable. The Arduino systems and ambient monitor can communicate with the LabVIEW program in the SCM PC via USB. The LabVIEW program received the sensor values every 5 seconds and displays the values with several graphs, which show the recent 8 hours of data. Figure 4 shows a screenshot of part of the LabVIEW display. It includes a total of four SICK ultrasonic level meters, six Arduino systems, eight RTDs, one ambient monitor. Note that the full display includes two relative pressure meters, and one flow meter also. And Fig. 5 shows the NI modules with a dedicated NI crate.

Figure 4: A screenshot of the SCM system.

Figure 5: Connection scheme with the NI modules.
3.2 High Voltage Control Monitor

The CAEN SY1527LC crate can be communicated with the CAEN OPC server to transfer information. A LabVIEW program installed in a High Voltage Control Monitor (HVCM) PC supplies communication with the CAEN OLE for the OPC server, therefore it is easy and convenient to call necessary information from the Crate and HV supplier modules via the OPC server. In addition, the LabVIEW calls the temperature of each HV supplier module, preset HV, supplied HV, and current of each channel. For the convenience, we drew the planar figure of the detector and positioned 120 PMTs marked with circles. Each circle depicts different colors depends on the difference between the preset HV and supplied HV. It shows green color if the difference is less than 10 V, or yellow color if the difference is between 10 to 20 V, or orange color if the difference is between 20 to 30 V, or red color if the difference is greater than 30 V. Figure 6 shows a screenshot of the HVCM. The temperature of each supplier board is also shown on the bottom left of the screenshot.

![Figure 6: A screenshot of the HVCM system.](image)

3.3 Database

The MySQL database is connected with the LabVIEW program via network and stores the SCM and HVCM value. For the SCM case, we made only one table to store every sensor values every 30 seconds with time. For the HV case, we made each table for each channel of the HV supplier. Every 30 seconds the preset HV value, supplied HV value, current, and Time are stored in each table. Additionally, the temperature of each HV supplier module is also recorded in a dedicated table.
4 Grafana

We adopted the Grafana, which is one of the widely used graphic tools, to track each sensor’s values for the SCM and to track supplied HV and current values for the HVCM, and to set the threshold values for an alert. LabVIEW also can handle the same function such as the graphs and the warning system, however, it is relatively inconvenient to change the time scale of graphs while running. The Grafana can access to the MySQL database and can request the values from a MySQL query. It is easy to change the time scale with one click and has an embedded warning system [14]. The Grafana supplies both the chronological graph and a single number with several colors. Figure 7 shows a screenshot from part of the Grafana for the SCM including the alert test. Both the chronological panel and the latest data with color panels are shown. If the recorded number in the database is larger than the threshold value, the panel color is changed from green to red, and the Grafana sends a warning message through email and LINE (online chat tool) automatically. The readout and warning test shows promising results. For the HVCM, the Grafana displays several chronological graphs for the supplied HV and current of each channel because the LabVIEW shows only current status with color. If the supplied HV becomes less than 5 V at any channel, the Grafana sends a warning message via email and LINE and repeated at every minute. Fig. 8 shows a screenshot from part of the Grafana for the HVCM.

Figure 7: Example screenshot from part of the Grafana for the SCM. Top panel shows the chronological graph of several sensors, and bottom colored panels show the latest value of each sensor and some combination (difference in this case) between sensors. If either the sensor value or the difference between certain sensors is larger (or smaller which is depends on the setting) than the threshold value, the panel color is changed to red and the system sends warning email and/or LINE message automatically.

5 Conclusion

The JSNS$^2$ experiment prepared ultrasonic level meters, relative pressure meters, RTDs, a flow meter, and an ambient sensor for the SCM to monitor the detector and nearby status. The CAEN system is reused for the HV. The LabVIEW program, the MySQL database, and the Grafana tool are combined to one system to handle the sensors and the HV supplier modules, to store and monitor the data, and to set the threshold values for the warning. The overall test shows promising performance for the JSNS$^2$ experiment.
Figure 8. Example screenshot from part of the Grafana for the HVCM. The left panel shows the supplied HV of 24 channels, and the right panel shows the current of 24 channels. If the supplied HV value of any channel becomes less than 5 V, the Grafana sends a warning email and LINE message at every minute.

Acknowledgements

We thank the J-PARC staff for their support. We acknowledge the support of the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and the JSPS grants-in-aid (Grant Number 16H06344, 16H03967), Japan. This work is also supported by the National Research Foundation of Korea (NRF) Grant No. 2016R1A5A1004684, 2017K1A3A7A09015973, 2019R1A2C3004955, 2016R1D1A3B02010606, 2017R1A2B4011200 and 2018R1A1B07050425 funded by the Korea Ministry of Science and ICT. Our work have also been supported by a fund from the BK21 of the NRF. The University of Michigan gratefully acknowledges the support of the Heising-Simons Foundation. This work conducted at Brookhaven National Laboratory was supported by the U.S. Department of Energy under Contract DE-AC02-98CH10886. The work of the University of Sussex is supported by the Royal Society grant no. IESAR3/170385.

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