

Slow control and monitoring system at the JSNS²

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The Sterile Neutrino Search at the J-PARC Spallation Neutron Source (JSNS²) experiment aims to search for sterile neutrino oscillations using a neutrino beam from muon decays at rest. The JSNS² detector contains 17 tons of 0.1% gadolinium (Gd) loaded liquid scintillator (LS) as a neutrino target. Detector construction was completed in the spring of 2020. A slow control and monitoring system (SCMS) was implemented for reliable control and quick monitoring of the detector operational status and environmental conditions. It issues an alarm if any of the monitored parameters exceed a preset acceptable range. The SCMS monitors the high voltage of the photomultiplier tubes, the LS level in the detector, possible LS overflow and leakage, the temperature and air pressure in the detector, the humidity of the experimental hall, and the LS flow rate during filling and extraction. An initial 10 days of data-taking with a neutrino beam was done following a successful commissioning of the detector and SCMS in 2020 June. In this paper, we present a description of the assembly and installation of the SCMS and its performance.
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Subject Index C44, C50

1. Introduction

The Sterile Neutrino Search at the J-PARC Spallation Neutron Source (JSNS²) experiment aims to search for sterile neutrino oscillation with mass-squared difference Δm^2 near 1 eV^2 at J-PARC [1]. The experiment uses a pulsed neutrino beam created from muon decays at rest, where the muons are produced from collisions of a 3-GeV proton beam on a mercury target. Based on this source, a sensitive search for muon antineutrino oscillations to electron antineutrino is possible. The JSNS² detector is located on the third floor of the Material and Life Science Facility (MLF), 24 m away from the target neutrino source [2].

The detector consists of 17 tons of Gd-loaded liquid scintillator (Gd-LS), as a neutrino target, in an acrylic vessel, and 31 tons of unloaded LS as a gamma-catcher and a veto, in a stainless steel container surrounding the target. The gamma-catcher and veto are optically separated. Scintillation light produced in the target and gamma-catcher regions is detected by an array of 96 10-inch PMTs [3]. Light produced in the veto region is detected by an array of 24 10-inch PMTs. Figure 1 shows an overview of the JSNS² detector.

High voltage is supplied to each of the 120 photomultiplier tubes (PMTs) individually and can be monitored and adjusted to maintain their uniform and constant gains. Since the MLF uses a highly irradiated mercury target under the JSNS² detector, the safety requirement for the JSNS² detector is quite stringent. The flammable LS must be treated carefully according to the Fire Law in Japan. The LS level in the detector is monitored by ultrasonic sensors. Several stabilization containers are installed on the top of the detector, as shown in Fig. 2, for the purpose of preventing the Gd-LS from overflowing due to its thermal expansion. The Gd-LS levels in the stabilization containers are also monitored by ultrasonic sensors. The temperature and pressure in the detector and the humidity of the experimental hall are measured and monitored by installed sensors. The detector is surrounded by the spill tank and any LS spill is detected by ultrasonic sensors and web cameras.

The third floor of the MLF is a maintenance area for the spallation neutron target and beam line equipment. The JSNS² detector has to be relocated from the third floor during maintenance periods, typically from July to September. For detector relocation, the LS must be filled into, or extracted

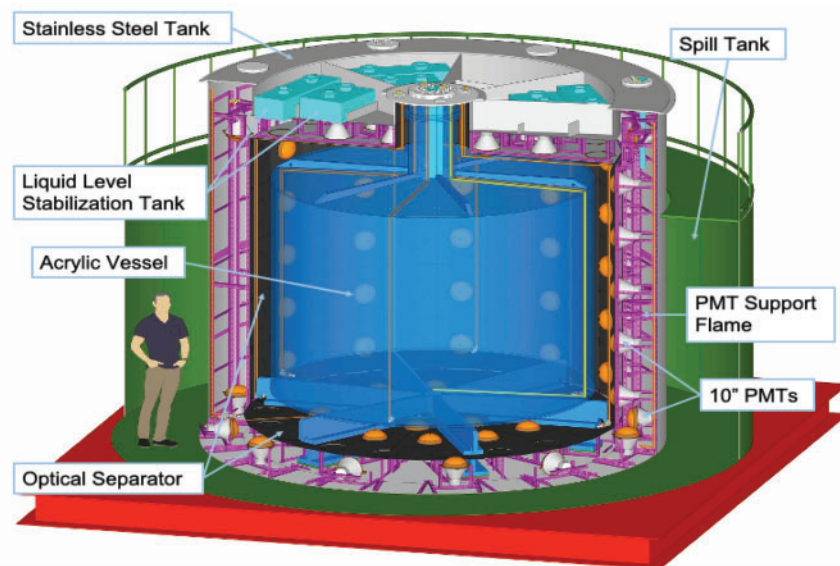


Fig. 1. Configuration of the JSNS² detector.

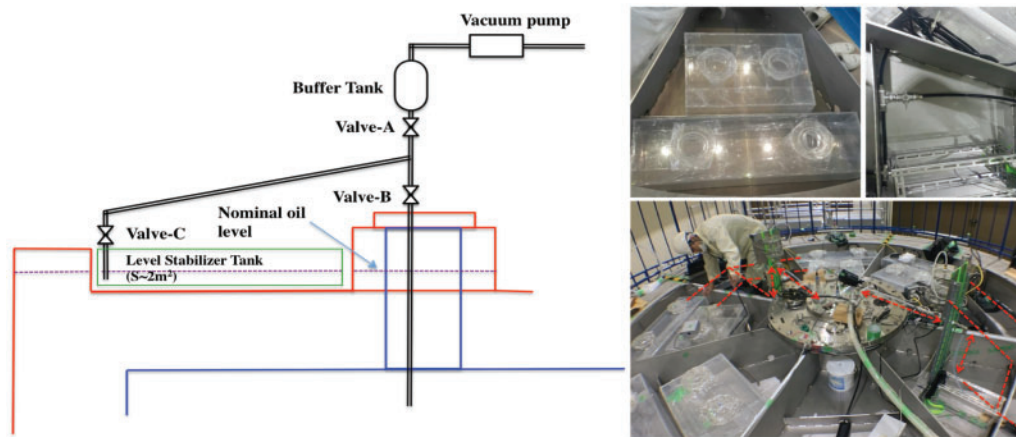


Fig. 2. Conceptual design of the stabilizer container (left) and photos taken after deployment on the top lid of the detector (right). In the left-hand design, the red, blue and green lines indicate the stainless steel tank, the target acrylic vessel, and the stabilizer container, respectively. The right-hand pictures show a set of two acrylic containers (top left), connecting pipes between container sets (top right), and four sets of containers installed on the top lid of the detector (bottom). The red dashed arrows represent the pipes connecting the stabilizer containers to the acrylic vessel inside the detector via the inverse siphon system.

from, the detector. The LS flow rate and level in the detector are carefully monitored during filling and extraction.

After an overview of the slow control and monitoring system (SCMS) in Sect. 2, we describe the high voltage (HV) control and monitoring in Sect. 3. Monitoring of the LS level in the detector, possible LS overflow and leakage, and LS flow rate during filling and extraction are discussed in Sect. 4. Section 5 details our system for monitoring the temperature and pressure in the detector and experimental hall. Visualization and display of the SCMS data are discussed in Sect. 6.

2. Overview of SCMS

The SCMS provides reliable control and quick monitoring of the operational status and environmental conditions of the detector. The SCMS can also issue alarms if any monitored values exceed a preset range, so that immediate maintenance can be undertaken. As described in the previous section, the system includes the control and monitoring of HV supplied to PMTs, and the monitoring of the LS level in the detector, possible LS overflow and leakage, the temperature and air pressure in the detector, the humidity of the experimental hall, and the LS flow rate during filling and extraction. The data acquired from the various sensors are delivered to a client program via a local network. The LabVIEW-based client program [4] records the data into a MySQL [5] database once every 30 seconds and displays the monitoring system's data for on-site experts. Outside the MLE, Grafana [6] receives data from the client program, displays the detector's current status and its environment, and generates alarms and control signals as needed. Figure 3 shows a schematic drawing of the SCMS. Table 1 lists the sensors used for measuring various parameters and their readout modules.

The data acquired by several sensors are collected by readout modules and delivered to the LabVIEW client via USB cables. A National Instruments (NI) module 9216 [7] is used to read data out from the resistance temperature detectors (RTDs). An NI 9201 [8] reads analog voltage values from a number of sensors. An NI 9203 reads an analog current value from a flow meter. An NI cDAQ-9178 [9] crate houses these three NI modules and is connected to an SCMS PC via a USB

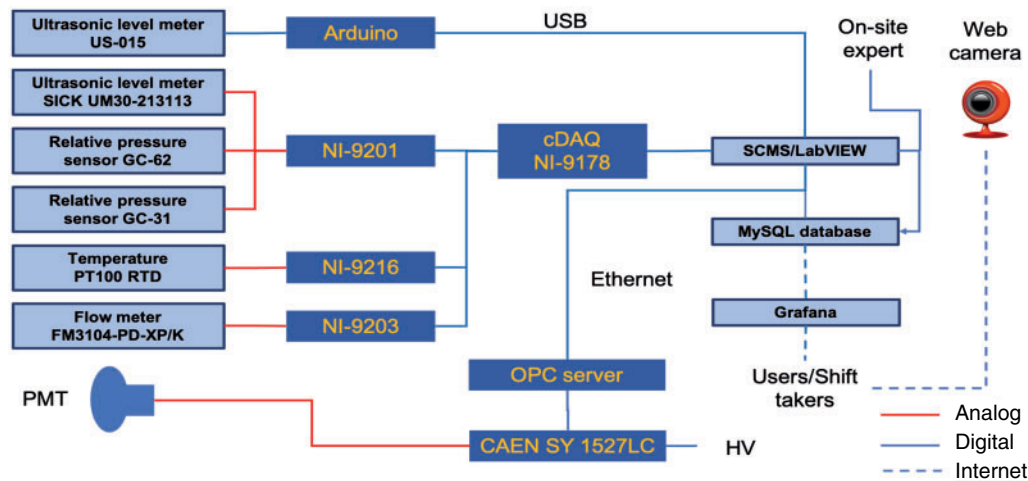


Fig. 3. Conceptual diagram of the JSNS² slow control and monitoring system. The red and blue solid lines represent analog and digital signals, respectively. Except for Grafana, all components are connected via the local network. The camera is connected to the internet and used for monitoring the current status of the detector in real time.

Table 1. Monitored parameters and readout modules for used sensors.

Sensor (Model ID)	Measured quantity	Readout module
CAEN OPC server with SY1527LC	PMT high voltage	Ethernet
Ultrasonic (SICK UM30-215113)	Liquid height	NI 9201
Ultrasonic (SICK UM30-213113)	Liquid height	NI 9201
Ultrasonic (HALJIA US-015)	Liquid height inside the spill tank	Arduino
Ultrasonic (HALJIA US-015)	Liquid height of the level stabilization	Arduino
Temperature (PT100 RTD)	LS temperature	NI 9216
Relative pressure (GC-62)	Pressure between chimney and veto volume	NI 9201
Relative pressure (GC-31)	Pressure between detector and laboratory	NI 9201
Flow meter (FM3104-PD-XP/K)	LS flow rate	NI 9203
Ambient sensor (TR73-U)	Laboratory temperature, humidity and pressure	RS232 to USB
Web camera	Liquid leakage inside oil protection wall	N/A

cable. LabVIEW was selected as a readout program because it interfaces well with the NI readout modules.

Several Arduino modules (described in Sect. 4.2) are used to read data from ultrasonic sensors in order to detect possible liquid spills and monitor the LS level in the stabilization containers, which are installed on top of the detector as shown in Fig. 2. These Arduino systems communicate with the LabVIEW program on the SCM PC via USB.



Fig. 4. An example screenshot of the LabVIEW display.

The LabVIEW program queries each sensor's measured value every 5 seconds and displays them over an 8-hour time span, sending the data to a MySQL database at the same time. The LabVIEW program can display information about the current status of the detector on the screen. The information displayed includes the liquid levels from four SICK ultrasonic sensors (described in Sect. 4.1) and six Arduino systems, the detector temperatures from eight RTDs (resistance temperature detectors), the detector pressure, and the humidity in the experimental hall. It also shows the liquid flow rate during filling and extraction. Figure 4 shows screenshots of a typical part of the LabVIEW display, which includes the RTD temperatures, the liquid levels from the ultrasonic sensors, and the experimental hall's temperature and humidity.

The LabVIEW program communicates with a MySQL database over a network connection to store the slow control and HV values in a single table every 30 seconds. The current HV value of each PMT is recorded on its own table. The temperature of each HV supplier module is stored in a dedicated table.

This system can be accessed through the network to display or record both current and historical data. The SCMS client applications allow users to manage and access the status of the experiment through a flexible graphical-user-interface based tool, Grafana. Figure 5 shows the NI readout modules and the NI crate.

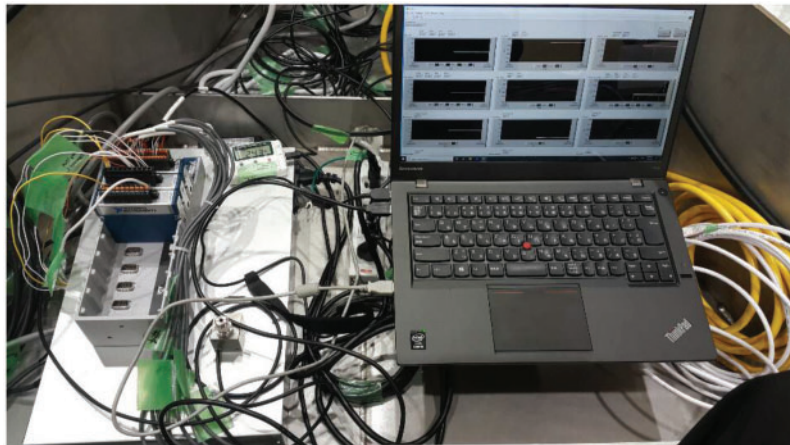
Table 2 shows each parameter's requirements and the performance required for SCMS to undertake the JSNS2 experiment successfully.

3. High voltage control and monitoring

The CAEN SY1527LC crate with six A1535 modules [10] obtained from the Double Chooz experiment are reused to supply HV for 120 PMTs. A CAEN A1535 module can supply 24 different

Table 2. Summary of the requirements for measuring SCMS parameters and the precision of the sensors.

Parameter	Requirement	Performance
High voltage	Control PMT HV and issue an alarm for an abnormal channel	$\pm 0.5 \text{ V} \pm 0.3\%$ (reading) $\pm 0.25 \text{ V} \pm 0.3\%$ (setting)
Liquid temperature	Detect abrupt change before a possible liquid overflow	$0.15 \pm 0.002T[^\circ\text{C}]$
Liquid height	Ensure difference between target and gamma-catcher is less than 15 cm	UM30-213113: $\pm 1\%$ UM30-215113: $\pm 1\%$
Detector air pressure	Ensure difference between the detector inside and outside less than 20 kPa	GC31: $\pm 1.0\%$ GC62 : $\pm 1.0\%$
Liquid flow rate	Adjust liquid filling and extraction speed to ensure liquid level difference between target and gamma-catcher is less than 15 cm	
Oil leakage	Detect any oil leak as early as possible	US-015 : $\pm 0.1 \text{ cm} \pm 1\%$
Ambient parameters	Monitor environmental conditions possibly causing detector operation	TR-73U: Temperature: $\pm 0.3 \text{ }^\circ\text{C}$ Humidity: $\pm 5\% \text{ RH}$ Pressure: $\pm 1.5 \text{ hPa}$

**Fig. 5.** Analog modules (NI-9201, 9216, and 9203) installed in the NI cDAQ 9178 chassis (left) and SCMS system test PC (right).

voltages up to 3.5 kV for each channel. The CAEN operational process control (OPC) server is used to control and communicate with the HV modules [11].

The CAEN SY1527LC crate is accessed via the OPC server from a dedicated, LabVIEW-based, HV control and monitoring (HVCN) program. The HVCN program downloads a preset HV value for each channel, and stores the currently supplied HV of each channel and the temperature of each HV module. The HVCN program also displays the status of supplied PMT HV on a map of PMT locations. Figure 6 shows a screenshot of the monitored HV status using the HVCN program. The color of each circle represents the HV status based on the difference between the preset and the currently supplied values.

4. Liquid scintillator monitor

As described earlier, the Gd-LS and LS levels in the detector and stabilization containers are monitored by ultrasonic sensors. Possible liquid spill within the spill tank surrounding the detector is

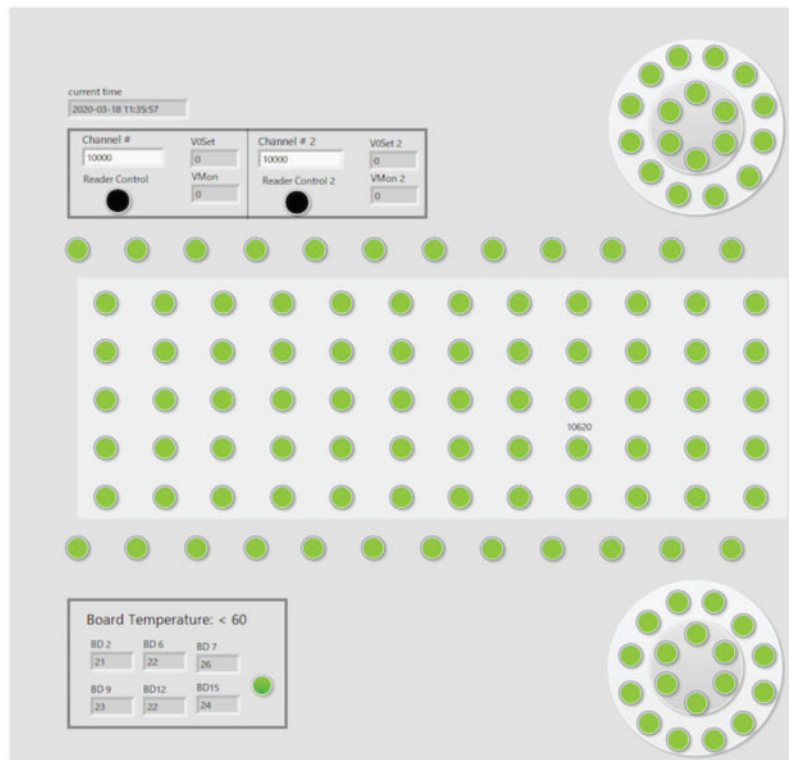


Fig. 6. Screenshot of HVCM display. Each green circle indicates that the PMT voltage is within a 10 V difference from its preset value. The temperature of each HV module is shown in the bottom left.

monitored by ultrasonic sensors and web cameras. The temperature of the LS is monitored by 8 sensors installed inside the detector. The liquid flow rate and liquid levels in the detector are monitored during filling and extraction as well. Several kinds of ultrasonic sensors are used to measure the liquid levels according to their precisions and operational ranges. Figure 7 shows the installed sensor locations.

4.1. Liquid scintillator level monitor

SICK ultrasonic level meters [12] are used to monitor for the levels of Gd-LS and LS in the detector. A pair of different sensors is installed on the detector chimney for the Gd-LS level monitoring and on the veto flange for the LS [13,14]. The measurement of liquid level by ultrasonic sensors is interrupted by cables through the inlet and the PMT structure in the detector. An acrylic pipe with the sensors attached to it is used to avoid the interruption. The end of the acrylic pipe is carefully polished to avoid unnecessary reflection of ultrasonic waves. Each liquid level meter provides an analog voltage output from 0 to 10 V, proportional to the measured distance to the liquid surface; an NI 9201 module reads the analog voltage output. Each level meter also displays the measured distance on an LED screen. Figure 8 shows a distribution of measured liquid levels during filling, data-taking, and extraction modes.

4.2. Liquid scintillator leak monitor

There are four additional ultrasonic level sensors for monitoring the interior of the spill tank, and two additional ultrasonic level sensors for monitoring the liquid level inside the stabilization containers. The US-015 [15] ultrasonic sensor is used to detect even a relatively small amount of liquid in the

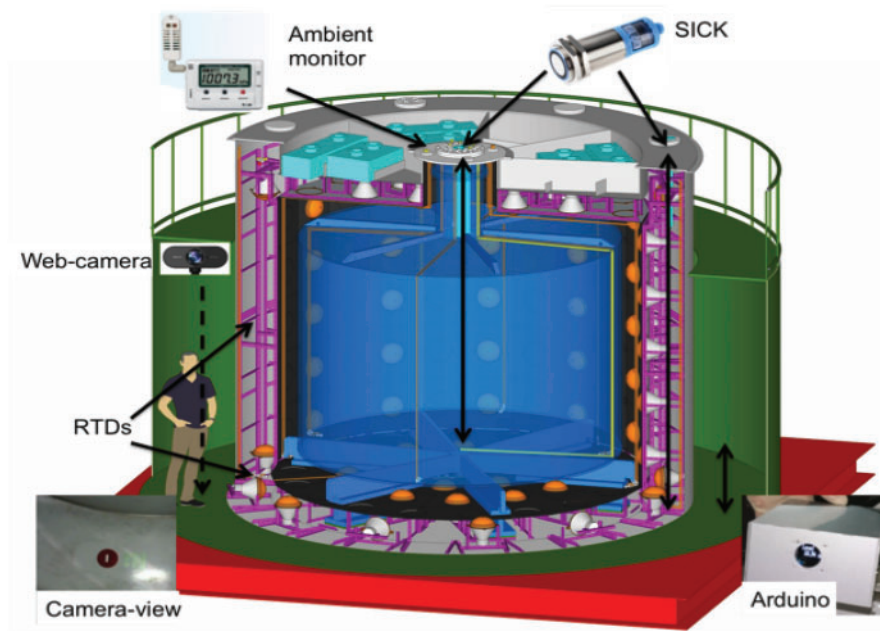


Fig. 7. Locations of installed sensors.

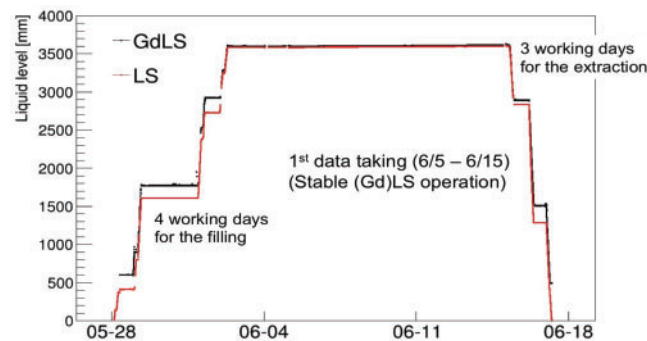


Fig. 8. Variation of liquid level in the detector measured by ultrasonic sensors during liquid filling, data-taking, and liquid extraction.

spill tank. The US-015 is well-suited for this because its operational range is from 20 mm to 4000 mm and its resolution is roughly 1 mm. The sensors are installed about 10 cm from the floor, facing down, as shown in Fig. 7. The sensors for the stabilization containers must be sensitive to the distances from 50 mm to 300 mm, and thus the US-015 sensors are also used for monitoring the liquid level inside the stabilization containers.

The US-015 sensors are read out by an Arduino I2C Uno Rev3 module [16], a micro-controller capable of analog-to-digital conversion. The Arduino module sends data to the SCM PC over a USB connection. The obtained data are displayed on a connected 0.96-inch organic LED that is produced by SUNHOKEY Electronics Co. Ltd. [17]. Figure 9 shows a liquid level monitoring device consisting of an ultrasonic sensor, an Arduino readout module, and an OLED display for a stabilization container [18]. It also shows a liquid level monitoring device for the spill tank.

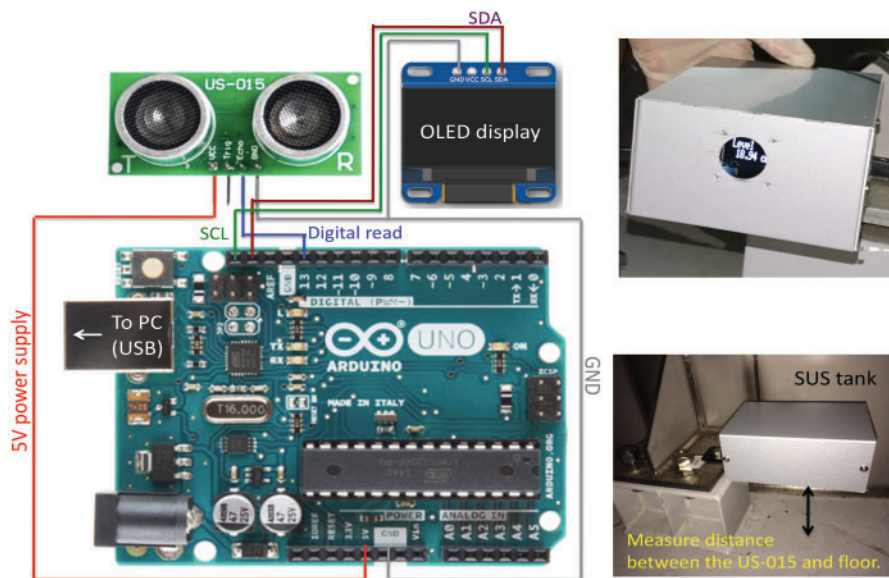


Fig. 9. Liquid level monitoring device consisting of a US-015 ultrasonic sensor, an Arduino I2C UNO readout module, and an OLED display. A US-015 has a digital output related to the pulse height of information about the distance, and the SCMS reads digital values transmitted from Arduino via USB cable. The connection diagram for the device is shown in the left-hand image. The assembled device in its housing is shown in the top right-hand photo. The bottom right-hand photo shows the device installed for the spill tank.

4.3. Monitoring for liquid scintillator filling and extraction

As described earlier, the JSNS² detector is installed on the third floor of the MLF building. The area is reserved for regular maintenance of the mercury target and beam line equipment. During the maintenance period, the detector must be removed from the MLF and stored elsewhere. The (Gd-)LS must be filled or extracted before installation or relocation, respectively. Both Gd-LS and LS levels inside the detector must be maintained as evenly as possible to minimize the stress on the acrylic vessel.

An FM3104-PD-XP/K [19] flow meter is used to measure the liquid flow rate into and out of the detector during filling and extraction, respectively. A frequency inverter for the pump is used to modulate the flow rate of the liquid. The flow meter displays the measured flow rate on an LED display and provide an analog current output from 4 to 20 mA, proportional to the flow rate. An NI 9203 module reads and digitizes the analog current output.

5. Monitors for detector temperature, pressure and environmental condition

5.1. Detector temperature monitor

Thermal expansion of the liquid scintillator could result in overflow from the detector. Eight stabilizer containers provide buffer volumes for the thermal expansion of Gd-LS. However, the buffer volumes could be overwhelmed in the case of the inverse siphon being broken, so the temperature inside the detector is monitored by eight PT100 RTD sensors installed in the veto region. Four RTDs are installed in the detector's bottom region, and another four RTDs in the middle barrel region. An NI 9216 module reads measured temperatures from the RTDs. Figure 7 shows their installed sensor locations.

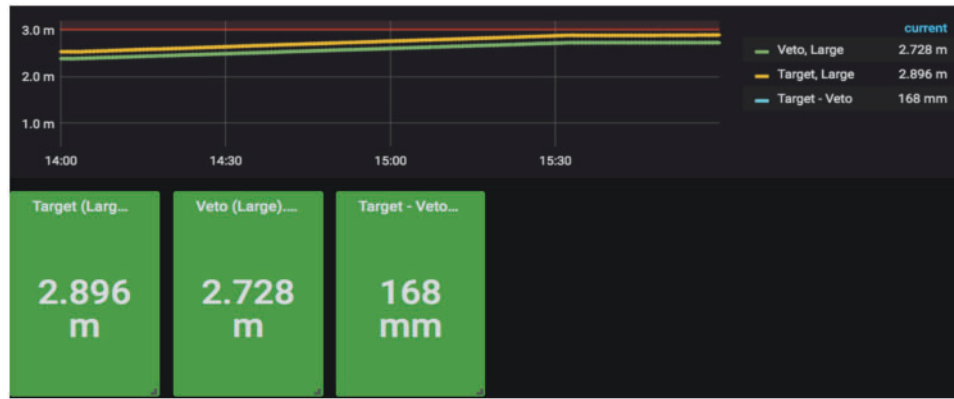


Fig. 10. Screenshot of SCMS display by Grafana during liquid filling. The top panel shows a chronological graph of measured liquid levels and their difference inside the detector, and the bottom colored panels show the latest results for comparison.

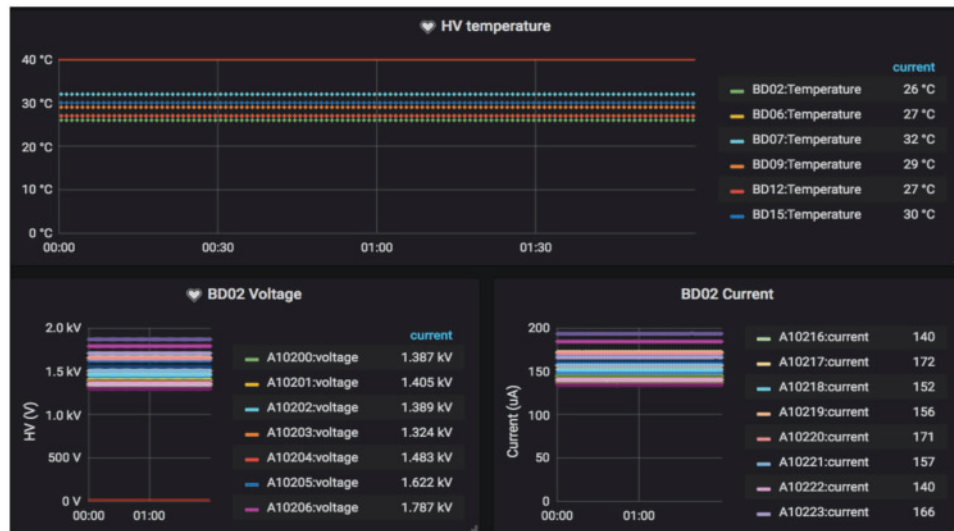


Fig. 11. Screenshot of the HV control and monitoring display by Grafana. The top panel shows the temperature of each HV supply module. The bottom left-hand panel shows the supplied HV of 24 channels, and the bottom right-hand panel shows the electric currents of the 24 channels.

5.2. Detector pressure monitor

The JSNS² detector is hermetically sealed to reduce the exposure of the (Gd-)LS to oxygen. The air tightening allows pressure differences to develop between the detector and the surrounding atmosphere. The stainless steel tank is strong enough to withstand pressure differences up to 20 kPa [20]. Two types of relative pressure meters, GC-31 [21] and GC-62 [22], are installed to monitor the pressure difference. The effective ranges are 100 kPa for GC-31 and 2 kPa for GC-62. The GC-62 sensor monitors the air pressure difference between the target chimney and the veto region. The GC-31 sensor measures the air pressure difference between the detector inside and outside. The pressure sensors provide a voltage output of 1 to 5 V proportional to the measured pressure difference. The output voltages are read out by the NI 9201 module.

5.3. Ambient sensor

A TR-73U sensor [23] is used to monitor environmental conditions around the detector. The sensor measures the temperature, humidity, and atmospheric pressure in the experimental area near the detector. The obtained data are read out by the LabVIEW program via an RS232 connector adapted to USB. The measured results are also displayed on an LCD panel.

6. Visualization of monitoring data

A Grafana graphical user interface is used to display the data recorded in the MySQL database and issues an alarm if necessary. Figure 10 shows a screenshot of the SCMS display during liquid filling. It displays the measured liquid levels and their difference. If the difference exceeds a preset threshold, the panel color changes to red and the Grafana sends warning e-mails and SNS messages. Figure 11 shows a screenshot of the monitored HV values and temperatures of HV supply modules. If the measured HV value of any channel becomes zero, Grafana displays an alarm signal and sends warning emails and SNS messages.

7. Summary

The JSNS² detector was completed and is operational for data-taking in search of sterile neutrino oscillation at J-PARC. For reliable control and quick monitoring of the detector's operational status, we have successfully installed various sensors with appropriate readout modules and a LabVIEW-based monitoring display using a Grafana GUI. The sensor readout data are recorded into a MySQL database. The SCMS also issues alarms to alert users if any of the monitored values are outside of their preset range. The first JSNS² run was completed in 2020 June with successful operation of the SCMS. This demonstrates a reliable and robust SCMS performance for the JSNS² experiment.

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