

Remote Device Control and Monitor System for the LHD Deuterium Experiments

Hideya Nakanishi^{a,b,*}, Masaki Ohsuna^a, Tatsuki Ito^a, Miki Nonomura^a, Setsuo Imazu^a, Masahiko Emoto^a, Chie Iwata^a, Masanobu Yoshida^a, Mitsuhiro Yokota^a, Hiroya Maeno^a, Miwa Aoyagi^a, Hideki Ogawa^a, Osamu Nakamura^a, Yoshitaka Morita^a, Tomoyuki Inoue^a, Kiyomasa Watanabe^a, Katsumi Ida^{a,b}, Seiji Ishiguro^{a,b}, Osamu Kaneko^{a,b}

^aNational Institute for Fusion Science (NIFS), Toki, Gifu 509-5292, Japan.

^bDept. Fusion Science, SOKENDAI (The Graduate University for Advanced Studies), Toki, Gifu 509-5292, Japan.

Abstract

Upon beginning the LHD deuterium experiment, the opportunity for maintenance work in the torus hall will be conspicuously reduced such that all instruments must be controlled remotely. The LHD data acquisition (DAQ) and archiving system have been using about 110 DAQ front-end, and the DAQ central control and monitor system has been implemented for their remote management. This system is based on the “multi-agent” model whose communication protocol has been unified. Since DAQ front-end electronics would suffer from the “single-event effect” (SEE) of D-D neutrons, software-based remote operation might become ineffective, and then securely intercepting or recycling the electrical power of the device would be indispensable for recovering from a non-responding fault condition. In this study, a centralized control and monitor system has been developed for a number of power distribution units (PDUs). This system adopts the plug-in structure in which the plug-in modules can absorb the differences among the commercial products of numerous vendors. The combination of the above-mentioned functionalities has led to realizing the flexible and highly reliable remote control infrastructure for the plasma diagnostics and the device management in LHD.

Keywords:

LHD, deuterium experiment, DAQ, remote control and monitor, PDU

1. Introduction

The LHD (Large Helical Device) is planning to start deuterium experiments in 2017 [1]. After the beginning of deuterium experiments, the maintenance access to the torus hall will be conspicuously restricted so that all the intelligent instruments must be remotely controlled.

The LHD data acquisition (DAQ) and archiving system, called the “*LABCOM system*,” have been using about 110 front-end nodes [2]. Each front-end consists of modular digitizers, backplane chassis, and a computer which often has optical interface and peripheral devices. All of the front-ends must be remotely managed during the campaign of the deuterium experiment.

However, some electronic circuits or semiconductor elements are generally known to suffer the “single-event effect/error” (SEE) from the energetic D-D neutrons. SEEs are divided into groups: The Single Event Upset (SEU) is a non-destructive software error, but the Single Event Latch-up (SEL) or the Single Event Burn-out (SEB) are potentially destructive hardware errors [3].

In any case of a SEE, the software-based remote operation becomes ineffective to reset the non-responding fault device. Therefore, it is essential to be able to securely intercept or recycle the electrical power of the device for recovering from the peculiar malfunction, such as a SEE failure.

In our previous work, we have implemented a real-time progress monitoring system for the central management of the distributed DAQ nodes. The monitoring console also enables us to remotely command every node independently or all at once [4]. The distributed monitoring structure is based on the “multi-agent” model in which the agent process runs on every node to provide the real-time status and also to accept the remote command messages. Therefore, the communication protocol between them has been simply unified.

In this study, a centralized control and monitor system has been developed for a number of power distribution units (PDUs) installed for every DAQ node. Unlike the central monitoring system, it is difficult to unify the communication protocol among multi-vendors’ commercial PDU products. Therefore, the central PDU management system has adopted the plug-in structure in which the plug-in modules can absorb the differences among the products.

1.1. Present status of LHD data system

In the 17th annual campaign, the LHD has renewed the world record of acquired data amount in fusion experiments from 328.5 GB (2012) to 891.6 GB (2013) by a 48 min. long steady state plasma sustainment. In the short pulse operation whose duration is less than 10 s, about 23 GB/shot raw data are produced cyclicly in every 3 minutes. The LHD consequently has about 180 shots per day in the short pulse operation.

Figure 1 shows the increasing number of DAQ nodes simultaneously with the acquired raw data amount for each shot. Even

*Corresponding author; phone: +81 572 58 2232.

Email address: nakanisi@nifs.ac.jp (Hideya Nakanishi)

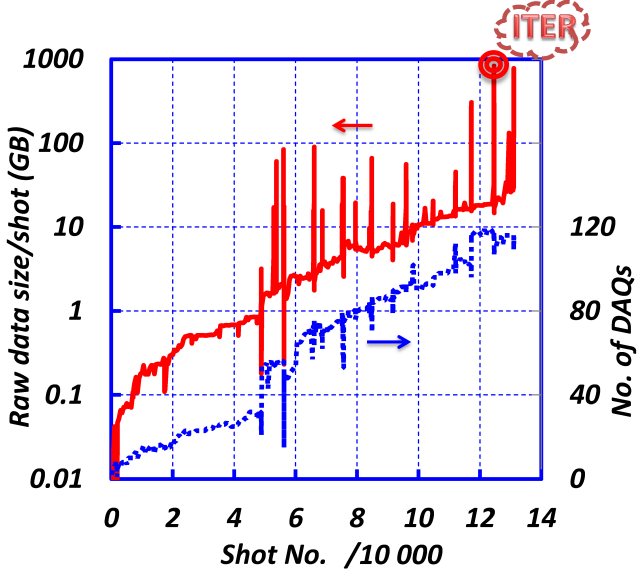


Figure 1: DAQ growth in LHD: The number of DAQ nodes has been increasing almost linearly and the acquired data amount per shot has been increasing exponentially for the past 17 years of operation. The data growth fits Moore’s Law very well. A double circle shows the highest amount of acquired raw data, 891.6 GB by about 40 min. long pulse experiment, which reaches the estimated data range of ITER.

though the number of nodes continues increasing linearly, the data amount continues growing exponentially. The data growth observed in the LHD fits Moore’s Law very well, doubling every 18 months [5].

The LHD is a fully superconducting fusion experimental device that intends to enable genuine steady state plasma sustainment. Therefore, the DAQ system of the LHD has been equipped with nonstop steaming acquisition and archiving capabilities. Each node can make full use of 1 Gbps Ethernet bandwidth with acquired raw data streaming output continuously [6].

2. Device Networks for Physics Measurements

For the LHD physics measurements, there are three device network layers:

1. PLC (programmable logic controller) network for inter-lock protection
2. Timing distribution network
3. Device operation and data transferring network.

The third layer is the so-called computer network based on the Ethernet. It has several commanding levels of device operations, which will be discussed in Section 4 below.

The second layer is the LHD timing distribution system which adopts the tree-structured dedicated fiber links from the master modulator to the terminal demodulators [7]. Their communication messages are also original. Not only the synchronized operation but also the standalone operation are enabled for local dry runs or calibration tests with the homemade “sequence emulator” commanding.

Even though the LHD continues to use some dedicated link media and protocols for the above-mentioned layer-1 and layer-2 networks, the current de facto standard is the Ethernet. The Ethernet has three major link media, each having its own advantages and weaknesses when used in the fusion laboratory environment:

1. UTP/STP cable ↔ EM noises, electrical isolation
2. Optical fibre ↔ radiation damages and malfunctions
3. Wi-Fi ↔ reliability, stability against EM noises.

Preparing for the high-performance deuterium plasma experiments, we are urgently required to verify the feasibility and reliability of each of these three media especially against the D-D neutrons and gamma-ray radiations. As for the optical fiber links, it is well known that opto-electronic devices will be easily influenced by energetic neutron and gamma-ray radiations compared to other semiconductor elements [8, 9]. Therefore, it will be inevitable for the optical Ethernet links to reduce the radiation influx by using well-designed radiation shields.

3. Wi-Fi Verification

Wi-Fi is a very popular technology which can easily provide the wireless LAN access [10]. Since Wi-Fi intrinsically provides the electrical isolations between devices, there will be considerable demands to use it in the torus hall. Therefore, we have made some test surveys in the LHD torus hall to verify the feasibility of the wireless LAN communication during the high-temperature fusion plasma experiments. The tests were conducted during the 18th LHD campaign in 2014–2015.

Figure 2 shows the survey results of the signal intensity distributions of 2.4 GHz and 5 GHz Wi-Fi bands, and shows that a single Wi-Fi access point is never able to cover the entire torus area. 5 GHz signal distribution typically shows that it hardly reaches the backside of some big obstacles, such as the LHD main body and the NBI launchers.

To measure the actual packet loss ratios during the plasma discharge experiments, we have installed some network equipment on the southeast stage (C), near the NBI#1 launcher, and on top of the LHD main body (T). Table 1 shows their packet loss ratios. In the 18th campaign, we only conducted hydrogen (H) plasma experiments. However, the packet losses were apparently increased during “H” plasma discharges.

The web camera placed on top of the torus had no response mostly during the plasma discharges. The PC and the web camera frequently showed more than 1% packet losses, and the other devices often indicated some significant errors even less than 1%.

In addition, the access point became non-responding twice probably due to discharge noise. Then, power recycling was needed to return to the normal condition.

According to the verification test results, we have concluded that standard Wi-Fi communication is not sufficiently reliable especially for the deuterium experiments having higher radiations than hydrogen plasmas.

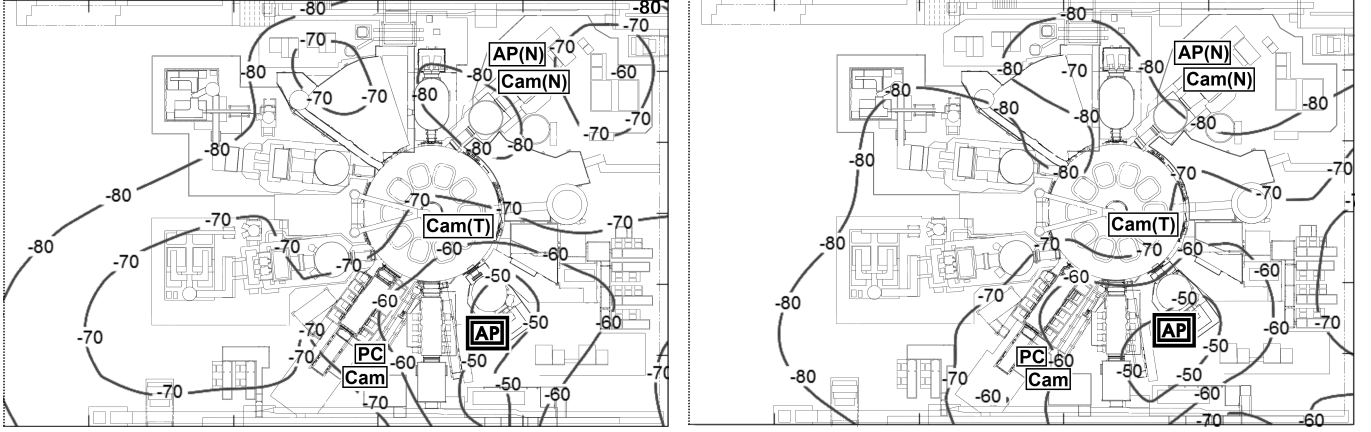


Figure 2: Wi-Fi signal strength (dBm) of 2.4 GHz (left) and 5 GHz (right) bands in the LHD torus hall: The doubly boxed “AP” shows the place of the Wi-Fi antenna, i.e. access point. Signals become weak (<-70 dBm) behind big obstacles. “PC” and “Cam” show the places of the test devices. See Table 1.

Table 1: Packet loss ratio of various devices measured by ping icmp echo reply. The dark gray columns show 100% loss, half gray > 1%, and light gray > 0.1%. AP means an access point, and Cam is a web camera. (C) is installed on the southwest stage, (N) is near NBI#1, and (T) is on top of LHD main body. “CamCtrl” shows the responding result for interactive remote commanding to the web camera. All web cameras used 2.4 GHz band whereas PC used 5 GHz. The installed places are shown in Fig.2.

Date	From	To	AP (C)	PC (C)	Cam (C)	AP (N)	Cam (N)	Cam (T)	CamCtrl (T)
10/31	-	-	0.000%	0.000%	0.000%	0.000%	0.000%	0.093%	OK
11/4	-	-	0.000%	0.000%	0.000%	0.000%	0.000%	54.950%	X
11/5	11:00	11:20	100.000%	100.000%	100.000%	100.000%	100.000%	100.000%	X
11/6	14:15	15:22	0.000%	17.701%	10.565%	0.076%	0.000%	100.000%	X
11/7	13:39	14:46	0.025%	30.051%	3.323%	0.024%	0.000%	100.000%	X
11/11	17:03	17:45	0.000%	1.968%	0.031%	0.000%	0.000%	100.000%	X
11/12	13:45	14:30	0.000%	11.375%	1.805%	0.076%	0.000%	27.177%	OK
11/13	10:47	11:10	0.000%	16.689%	0.874%	0.000%	0.000%	1.235%	OK
11/14	11:00	14:30	0.000%	11.773%	1.863%	0.075%	0.075%	2.459%	OK
11/17	9:05	13:20	0.049%	2.620%	1.087%	0.049%	0.049%	2.916%	OK
11/18	9:40	10:20	0.000%	0.440%	0.157%	0.094%	0.157%	0.251%	OK
11/19	13:26	14:49	0.000%	0.000%	1.112%	0.000%	0.000%	1.731%	OK
11/20	10:52	11:55	0.215%	0.215%	1.073%	0.215%	0.215%	1.288%	OK
11/21	9:48	11:29	0.137%	18.356%	1.644%	0.137%	0.137%	1.644%	OK
11/25	11:36	14:18	0.485%	0.485%	1.217%	0.730%	0.973%	100.000%	X
11/26	10:38	13:02	0.000%	0.172%	1.207%	0.172%	0.172%	100.000%	X
11/27	15:25	16:30	0.000%	0.000%	0.400%	0.000%	0.000%	100.000%	X
11/28	15:15	17:17	0.000%	0.000%	0.773%	0.110%	0.000%	100.000%	X
12/3	8:57	10:55	0.127%	0.127%	1.013%	0.000%	0.127%	93.797%	X
12/4	15:34	17:12	0.000%	0.000%	0.608%	0.000%	0.000%	0.365%	OK
12/5	8:38	10:24	0.134%	0.134%	0.538%	0.000%	0.134%	61.694%	X
12/9	16:03	18:04	0.000%	0.000%	0.333%	0.000%	0.000%	100.000%	X
12/10	11:02	13:48	0.173%	0.519%	1.038%	0.519%	0.346%	100.000%	X
12/11	14:50	17:09	0.257%	0.386%	0.386%	0.129%	0.257%	100.000%	X
12/12	15:06	16:53	0.377%	0.377%	1.132%	0.189%	0.377%	100.000%	X
12/15	9:13	11:14	0.000%	0.000%	0.700%	0.000%	0.000%	0.400%	OK
12/16	11:23	14:45	0.125%	0.250%	0.625%	0.250%	0.125%	100.000%	X
12/18	9:43	11:30	0.000%	0.125%	0.250%	0.000%	0.000%	100.000%	X
12/19	14:13	15:03	0.000%	0.262%	1.050%	0.000%	0.000%	100.000%	X
12/22	15:15	16:43	0.000%	0.129%	0.257%	0.000%	0.000%	100.000%	X
12/24	16:09	17:09	0.000%	0.000%	1.126%	0.000%	0.000%	100.000%	X
12/25	11:13	12:32	0.000%	0.000%	1.379%	0.000%	0.000%	100.000%	X
12/26	9:00	11:07	0.000%	0.000%	0.388%	0.000%	0.000%	0.485%	OK
1/6	11:16	12:32	0.000%	2.342%	0.180%	0.000%	0.000%	100.000%	X
1/7	11:31	13:50	0.000%	0.000%	0.500%	0.000%	0.000%	100.000%	X
1/8	11:30	14:25	0.000%	12.429%	0.286%	0.143%	0.143%	0.000%	X
1/9	11:28	13:45	0.000%	0.000%	0.100%	0.000%	0.000%	100.000%	X
1/13	11:20	14:38	0.000%	0.000%	1.400%	0.200%	0.200%	100.000%	X
1/14	9:35	11:51	0.000%	0.100%	0.100%	0.000%	0.000%	100.000%	X
1/15	10:10	13:00	0.000%	0.000%	0.400%	0.000%	0.000%	100.000%	X
1/16	11:16	13:30	0.000%	0.100%	0.000%	0.000%	0.000%	100.000%	X
1/20	11:20	15:30	0.163%	0.081%	0.569%	0.163%	0.163%	100.000%	X
1/21	10:13	13:00	0.000%	0.273%	0.455%	0.000%	0.000%	100.000%	X
1/22	16:39	18:25	0.000%	0.097%	0.484%	0.000%	0.000%	100.000%	X
1/23	14:15	16:45	0.094%	0.283%	0.755%	0.094%	0.000%	100.000%	X
1/26	11:24	17:10	0.095%	0.237%	0.853%	0.095%	0.095%	100.000%	X
1/27	9:49	13:13	0.067%	0.267%	0.600%	0.000%	0.000%	100.000%	X
1/28	10:30	15:00	42.417%	9.494%	0.493%	0.247%	0.247%	100.000%	X
1/29	9:09	11:35	30.000%	5.275%	4.066%	0.000%	0.000%	100.000%	X
1/30	9:30	12:30	0.000%	0.000%	0.690%	0.000%	0.000%	100.000%	X
2/2	9:30	13:15	0.000%	0.000%	1.270%	0.000%	0.000%	2.381%	OK
2/3	15:30	18:18	100.000%	3.300%	0.000%	0.000%	0.000%	100.000%	X
2/4	14:15	17:18	100.000%	0.257%	0.386%	0.257%	0.129%	23.552%	X
2/5	13:00	18:05	100.000%	0.200%	0.133%	0.133%	0.200%	100.000%	X

4. Commanding Levels on the Computer Network

The verification test results for wireless LAN communication happened to show that hardware reset is also necessary to restart the non-responding devices. Consequently, the following commanding levels can be defined for the device operation and the data transfer operation.

1. Software commanding level:

- Real-time monitor for status and progress
- Interactively change operation parameters and modes
- Report promptly regarding errors and warnings

2. Host/OS operation level:

- Start/stop/restart the application processes
- Kill abnormal or zombie processes
- Interactive recovery, if possible (by shell command)

3. Device control level:

- Power on/off/recycle the device
- For PCs, the remote console access would be favorable.

The first and second levels are on software-based operation and control, and only the third level can change the hardware condition. In every case, commanding the device individually and commanding all devices at once are both necessary for the device operation.

In previous work, we have already developed an integrated GUI console that enables the operator not only to monitor the progress reports of massively distributed DAQ nodes but also to command them individually or wholly at once for the daily operations [4]. Figure 3 shows the real view in which the operator can command on the first and second levels.

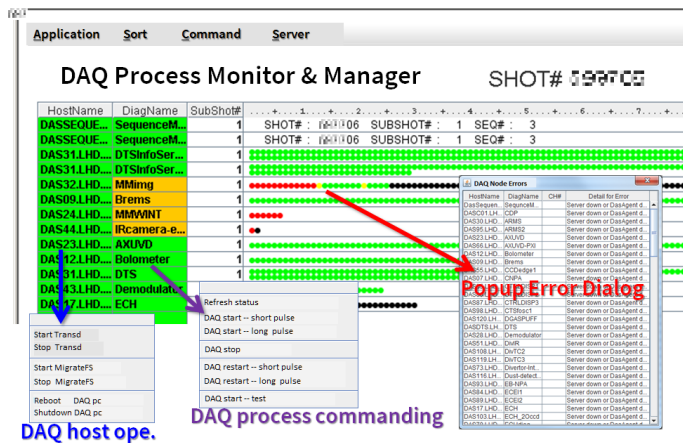


Figure 3: Integrated GUI of DAQ manager console [4]: This is a web-based Java applet program so that operators can watch the monitoring console from any place.

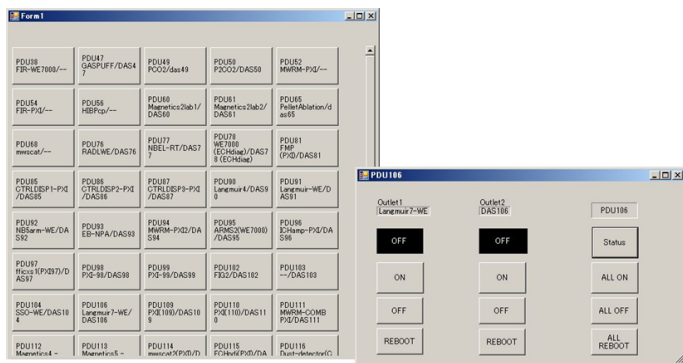


Figure 4: PDU manager GUI: This program has been developed as an MS Windows native application to guarantee the operational safety against any human mistakes and against remote intrusion through the network.

5. Remote Power Control

As described in the previous section, the DAQ manager console can execute software-based commanding. However, the hardware device operation may possibly cause a sudden stop of software processes and the operating system without any safe shutdown procedure. For the safe operation of the intelligent equipment, such as DAQ computers, we have decided to develop an independent GUI console for the above mentioned level-3 operation (See Figure 4).

As the software-based reset/reboot commanding would be inoperable for the frozen devices, it will be necessary to control the device power on/off remotely. Except for some intelligent PC servers equipping the IPMI port [11], the other PDU will be necessary for most of the electrical devices. Modern PDU products mostly have the Ethernet interface for providing the remote controllability through the network communication.

We have selected some PDU products for the variety of real use cases. The following commercial PDUs have been tested, and some are already installed in the LHD experiment.

1. ISA PDU-5115S, 15 Ax2, rsh/snmp
2. Meikyo RPC-2LC, 15 A (x2), telnet/web/snmp

3. Lantronix Spider Duo, 10 Ax1, telnet/ssh/web
4. Raritan PX2-5472JV-A1, 20A (x24), telnet/ssh/web/snmp

Because there is no systematic standard among many vendors' PDU control protocols, those products are quite different from each other. The central manager GUI must assimilate the differences of their commanding protocols and provide a unified interface to the operational user, as shown in Figure 4.

6. Summary

LHD is preparing for the high performance deuterium plasma experiments. In addition to monitoring and commanding the related processes on software, a new management GUI system has been developed for the device power on/off control via multi-vendor PDU commercial products. The PDU control GUI is implemented separately from the process operation GUI, taking the device safety against human mistakes and other risks into consideration.

During the last LHD plasma campaign, the Wi-Fi usability was examined in the torus hall. Testing revealed that Wi-Fi communication is not sufficiently reliable in the laboratory environment where fusion plasma experiments are conducted.

The combination use of software processes and hardware electricity management consoles has enabled us to maintain the devices with a wide flexibility. Hereafter, actual radiation shield should be properly designed to protect the intelligent devices on the spot.

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