Development of Simulated Remote Monitoring and Operation System under Unstable Electric Power Supply

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Abstract. In this study, a simulated remote monitoring and operation system was developed for an assumed remote area energy plant in a developing country with few skilled operators and unstable electric power supply. It is useful for skilled operators to be able to monitor and operate the energy system from a remote site. Moreover, low-power equipment is required for the Web server in order to reduce the electric power consumption of the remote monitoring system. The system has the function of remote monitoring of data obtained from sensors through a programmable logic controller (PLC), while the monitoring function is realized by a Web application. The PLC can be operated from a remote monitoring site. The simulated remote monitoring and operation system was constructed using an Internet connection and a virtual private network (VPN) connection. The Internet connection was used for open monitoring of acquired data by the public. The VPN was used for secure remote operation of the device on the plant side from a monitoring PC. The effectiveness of the developed system was confirmed though experiments with a simple simulated plant.

Keywords: *internet; PLC; remote monitoring and operation; remote energy system; VPN; web application.*

1 Introduction

In recent years, remote monitoring using communication technology has become common because of the development of network technology. For example, a remote monitoring and operation system using Open Platform Communications – Data Access (OPC DA), a standard interface for coordinating software that controls equipment at factories, was developed in [1]. OPC Unified Architecture (UA) is the sole recommendation for implementation of Reference Architecture Model Industrie 4.0 (RAMI4.0). A Web platform for the creation of human machine interfaces using low-cost devices with the OPC UA protocol was proposed in [2]. Moreover, data transfer from databases using SQL servers to OPC UA servers has been implemented, where the data can be viewed remotely by means of remote connections over the hypertext transfer protocol (HTTP) of OPC UA [3]. Home monitoring system with wireless communication through a

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general packet radio services network was designed in [4]. Remote monitoring systems of industrial plants through Internet-like networks have been developed [5,6]. Web-based remote monitoring systems have been investigated for various fields, such as solar power system monitoring [7-10], smart microgrid monitoring [11,12], industrial systems [13,14], and Wendelstein 7-X stellarator equipment [15].

In particular, the Raspberry Pi microcomputer has been adopted as a device for Web-based remote monitoring in a number of proposals in the last few years, as clear evidence of the increasing relevance of open-source and low-cost platforms [16,17]. Also, the relationship has been investigated between remote monitoring and servitization (a process of creating value by adding services to products) in four manufacturing companies, operating in the aerospace, the industrial equipment, the marine and the transportation sectors [18].

If the remote monitoring system is constructed using an Internet connection, there are security problems such as data falsification and unauthorized intrusion. Effective security strategies are required against any vulnerability of the supervisory control and data acquisition (SCADA) system. Various types of potential SCADA vulnerabilities based on real incidents reported in standard vulnerability databases are described in [19]. Also, if the remote monitoring system is constructed for a dedicated line, the system will be expensive. Hence, in this research, a virtual private network (VPN) connection was used for the remote monitoring system in order to realize security and cost reduction. VPN has already been applied for the security design of remote maintenance systems for nuclear power plants [20].

When operating a newly developed energy system in a developing country, such as the efficient conversion of bio-wastes to electricity by fuel cell and advanced hybrid ocean thermal energy conversion developed by the Science and Technology Research Partnership for Sustainable Development Program [21], it is difficult to locally operate the system by a skilled operator. Hence, remote monitoring and operation of the system is preferable. Moreover, in developing countries the electric power supply is often unstable and power outages frequently occur. In order to construct a remote monitoring system for a developing country, the unstable electric power supply must be taken into account.

In this research, a simulated remote monitoring system was developed for a remote area energy system. Both direct operation of the plant controller through VPN and Web-based remote monitoring of open data through the Internet were

investigated. Considering the unstable power supply in developing countries, a Raspberry Pi as a low-cost and low power consumption single-board computer, was adopted as the Web server. A data acquisition function for acquiring and storing measurement values such as temperature and current from sensors in the plant equipment was constructed using a programmable logic controller (PLC). The PLC can be operated from remote monitoring sites through the VPN connection. The plant can also be monitored by using a network camera over the VPN connection. An abnormality detection function for predictive maintenance and a history display function of acquired data to the remote monitoring system were also developed.

The rest of this paper is organized as follows: the remote monitoring and operation system is introduced in Section 2. Open remote monitoring through the Internet is described in Section 3 and secure remote operation through VPN in Section 4. The simulated remote monitoring and operation system constructed in this research is described in Section 5. Verification by an experiment involving remote monitoring and operation using the developed system is reported in Section 6 and discussed in Section 7. Finally, the conclusions are drawn in Section 8.

2 Remote Monitoring and Operation System

2.1 Objective

In energy plants in developing countries, where the electric power supply is often unstable and it is difficult to station skilled operators in remote areas, it is important to be able to capture and monitor the operational situation of the energy system from a remote place. For this reason it is useful to construct a remote monitoring and operation system for remote energy plant. The remote monitoring and operation system was constructed using easily available and relatively low-cost equipment.

In the system, the Internet is used to make operational states such as electric power generation available to the public while a VPN connection is used for secure operation of the equipment in the energy plant. A single-board computer is used as the Web server because it is low cost and has low electric power consumption. Moreover, general-purpose PCs are used for data acquisition from the PLC and the monitoring PC. The PLC is used for control and data acquisition of the energy plant.

2.2 Structure

The system configuration of the remote monitoring and operation system developed in this research is shown in Figure 1. The monitoring side includes a PC that monitors measurement data and the plant side includes devices installed in a remote energy plant for remote monitoring. On the plant side, a plant, a PLC, a PLC operation PC, a Web server, a network camera and a VPN router are installed, and a PLC, a PLC operation PC, a Web server and a network camera are connected to the VPN router.

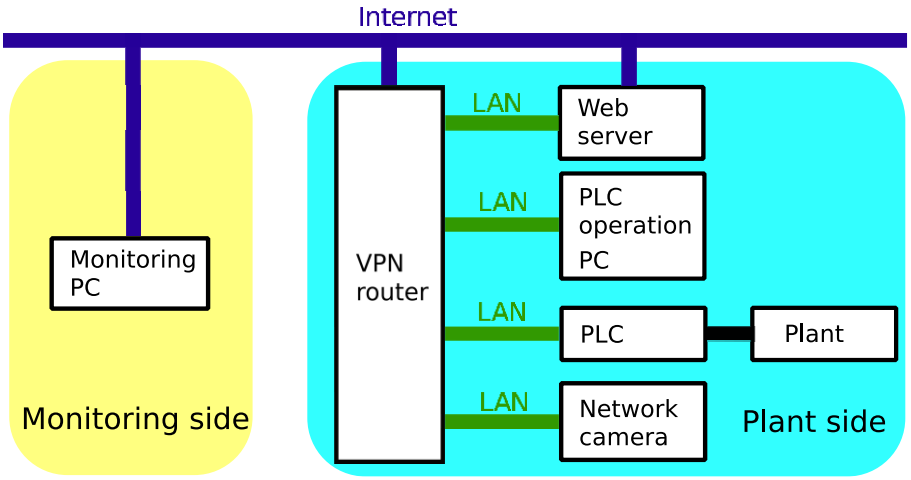


Figure 1 Network structure for remote monitoring.

The plant is controlled by the PLC and the measurement values of the sensors in the plant are accumulated in the PLC. The PLC is responsible for supervising, monitoring and controlling the plant, and the appropriate PLC is selected according to the plant. In order to operate the PLC, a PC is connected to the PLC through USB or Ethernet, so the programming, operation and execution of the functions of the PLC can be controlled by the PC. In this paper, this PC is called the PLC operation PC. Ethernet was adopted for the connection between the PLC and the PLC operation PC. The PLC operation PC can operate all the functions of the PLC via EtherNET/IP. In addition, since the PLC uses the file transfer protocol (FTP) server function, data can be sent from the PLC to the Web server via FTP by using the PLC operation PC.

Through the operation, the program for transferring the measurement data in the PLC to the Web server via PLC operation PC is executed. By accessing the Web server from the monitoring PC, the measurement data can be monitored through

a Web browser. In addition, the measurement data can be open to the public through the Web server. In the simulated remote monitoring system, a Raspberry Pi running Linux Raspbian 8 (Jessie) was used as the Web server in order to reduce power consumption and keep costs low.

The remote monitoring system is performed as follows: first, the measurement values of the sensors in the plant are obtained and acquired by the PLC as comma separated value (CSV) files. The CSV files are stored in the PLC operation PC. The accumulated CSV files are transferred to the Web server and by accessing the Web application in the Web server from the monitoring PC, the data can be displayed in the Web browser. Also, a network camera is installed for visually capturing the state of each local device. Monitoring of images acquired by the network camera is performed in the Web browser on the monitoring PC.

3 Open Remote Monitoring through the Internet

As shown in Figure 1, the Web server and monitoring PC are connected via the Internet. The Internet is used for open monitoring by the public of the measurement data in the plant, such as electric power generation. The Web application in the Web server is accessed from the Web browser in the monitoring PC, and the measurement data in the plant are displayed in the Web browser as well. Anyone can access the Web server through the Internet and get the published measurement data. The Web server is connected to two networks, i.e. a LAN and the Internet. The data to be released to the public are stored in the Web server from the data stored in the PLC through the PLC operation PC. On the monitoring side, the monitoring PC monitors the public data by accessing the Web server via the Internet using HTTP.

A Web platform for the creation of human machine interfaces (HMI) is constructed in the Web server so the user can easily access the public data through the Web browser in the monitoring PC via the Internet. The public data are displayed in the Web browser both in a schematic diagram of the plant and in a graph. The public data are updated in real time without any operation in the Web browser. Moreover, historical data can be also displayed in the Web browser.

Users on the monitoring side can easily access the public data and know the present status of the plant. As explained above, the data accessed from the Internet are public and anyone can access them. On the other hand, the remote operation through VPN is very different from the open monitoring through the Internet. The remote operation through VPN is fully accessed through the PLC, the PLC

operation PC, and the network camera. In the next section, the remote operation through VPN is described.

4 Remote Operation through VPN

In order to realize secure communication with devices on the plant side, a VPN connection using a VPN router is used. The Web server, PLC operation PC, PLC and network camera in the plant are connected to the VPN router. The VPN connection makes it possible to make a secure connection from the monitoring PC to the devices connected with the VPN router.

In order to execute and change the programs in the Web server and the PLC operation PC from the monitoring PC, the Web server and the PLC operation PC are connected to the VPN router. The PLC operation PC, the PLC program that saves the measurement data of the sensors can be operated remotely. Furthermore, it is possible to execute the program for transferring the measurement data in the PLC to the PLC operation PC and extracting the real-time data from the measurement data and transfer the real-time data from the PLC operation PC to the Web server by remote operation of the PLC operation PC. Also, the state of the plant can be confirmed by plant images from the monitoring PC by the network camera connected to the VPN router.

5 Simulated Remote Monitoring and Operation System

5.1 System Configuration of Simulated Remote Monitoring and Operation System

The system configuration of the simulated remote monitoring and operation system constructed in this research is shown in Figure 2. The equipment used in the simulated remote monitoring and operation system is shown in Table 1. The equipment used in the simulated remote monitoring and operation system is the same as that used in a newly developed energy system for developing countries.

A KV-7500 was used for the main body of the PLC, a KV- B16XC, KV-B16RC and KV-TP40 were used as expansion units of the PLC. A KV-B16XC was used as a unit for inputting the power supply and to operate data acquisition by a push button in the control panel in Figure 2. A KV-TP40 was used as a unit for temperature measurement by a thermocouple. Tables 2, 3 and 4 show the software used in the monitoring PC, in the PLC operation PC and in the Web server, respectively.

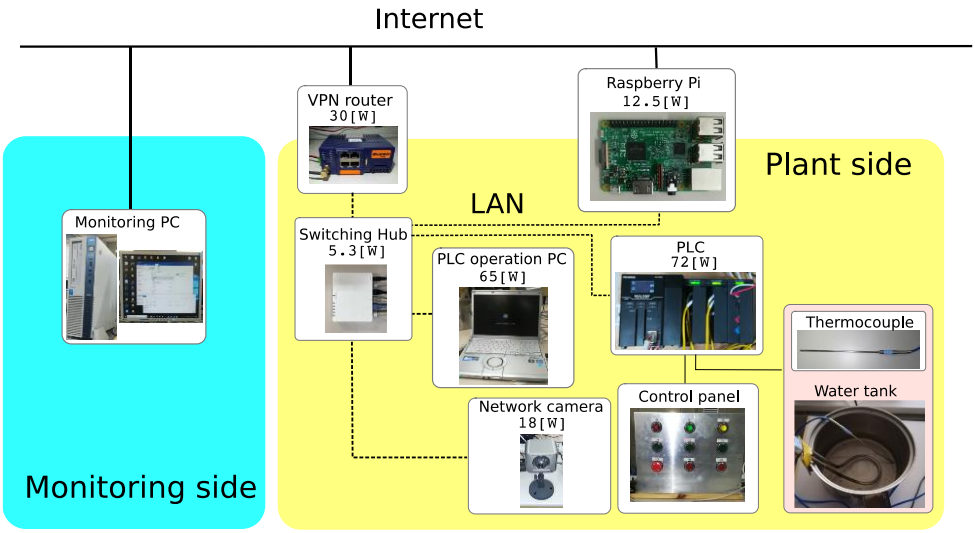


Figure 2 Structure of simulated remote monitoring system.

Table 1 Equipment used in simulated remote monitoring system.

Equipment	Manufacturer	Type
Monitoring PC	EPSON	MR4400E
VPN router	eWON	COSY 131
PLC (Main body)	KEYENCE	KV-7500
PLC Expansion unit	KEYENCE	KV-B16XC
PLC Expansion unit	KEYENCE	KV-B16RC
PLC Expansion unit	KEYENCE	KV-TP40
Thermocouple	KEYENCE	TF-C31 K
Network cameras	Panasonic	BB-SW172A
PLC operation PC	Panasonic	CF-S10
Web server	Raspberry Pi	3 Model B+

Table 2 Software used in monitoring PC.

Purpose	Software name
Operation system	Microsoft Windows 10 Enterprise 1803
Remote operation	Chrome Remote Desktop 63.0.3239.17
VPN connection	eCatcher 6.1.2
Network camera monitoring	Easy Setup 4.2.5.0
Browser	Microsoft Edge

Table 3 Software used in PLC operation PC.

Purpose	Software name
Operation system	Microsoft Windows 7 Professional Service Pack 1
Remote operation	Chrome Remote Desktop 63.0.3239.17
PLC operation	KV-STUDIO 9
Program execution	Command Prompt

Table 4 Software used in web server.

Purpose	Software name
Operation system	Linux Raspbian 8 (jessie) kernel 4.4.11-v7+
Web service	Apache2 2.4.10
FTP service	vsftpd 3.0.2

The local clocks of the PLC, PLC operation PC and Raspberry Pi were synchronized via the network time protocol (NTP) through a commonly used NTP server. In addition, operation related to data acquisition of the simulated remote monitoring and operation system could be performed with the control panel. By logging into the cloud-based VPN server (Talk2M) using software (eCatcher) from the monitoring PC, a VPN tunnel was established in the plant network. As a result, communication could be conducted from the monitoring PC to the VPN router through the VPN connection.

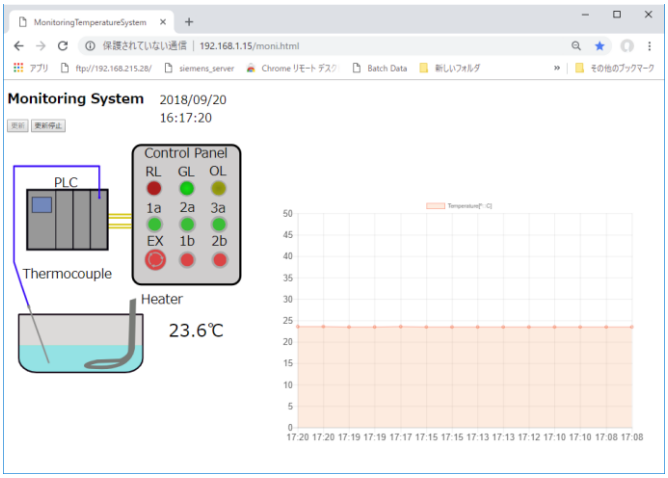
As shown in Figure 2, in the simulated remote monitoring system, the maximum power consumption of each equipment in the remote site was 12.5 [W] for the Raspberry Pi, 30 [W] (12 [V], 2.5 [A]) for the VPN router, 65 [W] for the PLC operation PC, 18 [W] (12 [V], 1.5 [A]) for the Ethernet transmission adapter for driving the network camera, 72 [W] (24 [V], 3 [A]) for the PLC, 5.3 [W] (5.3 [V], 1 [A]) for the switching hub, and 202.8 [W] for the total maximum power consumption.

5.2 Simulated Plant

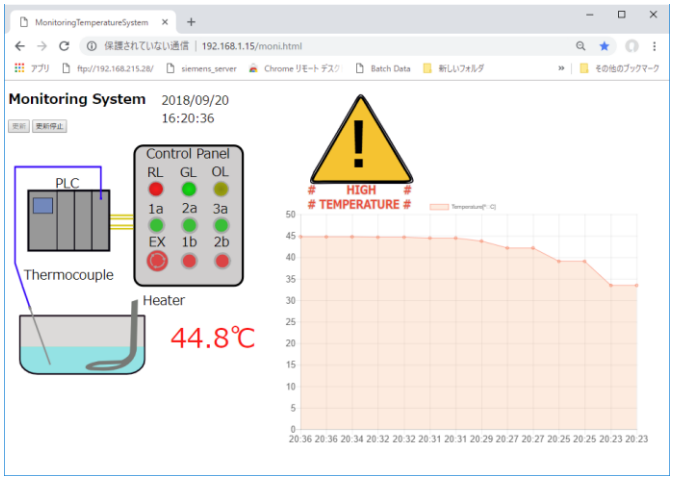
The monitoring target of the simulated remote monitoring system was the temperature of a water tank in the plant shown in Figure 2. The water temperature was measured with a thermocouple (TF-C31 K) to be published as measurement data. The temperature of the water tank could be controlled by heating with an aluminum heater and by pouring cold water into the water tank. An abnormality was defined by a temperature of the water tank of more than 35 [°C].

5.3 Web Application

The time required to update the display data in the Web browser was 1 [s] by using Ajax technology [22], while the Web browser used in the monitoring PC was Google Chrome. The measurement data were acquired by the PLC, recorded every 1 [s] in a CSV file, and monitoring was conducted. The display results of the Web browser are shown in Figure 3(a) and (b), displaying normal temperature and abnormal temperature respectively.



(a) Normal temperature



(b) Abnormal temperature

Figure 3 Screenshots of the Web browser as the Web application.

5.4 VPN Result

The PLC was used for measurement of the water tank temperature and collection of the measurement data. The PLC was operated by the PLC operation PC. Through the VPN connection in Figure 2, remote control of the PLC operation PC connected to the VPN router could be performed from the monitoring PC.

Chrome Remote Desktop installed on the Monitoring PC was used to remotely operate the PLC operation PC. The Web browser in which the remote control was performed is shown in Figure 4.

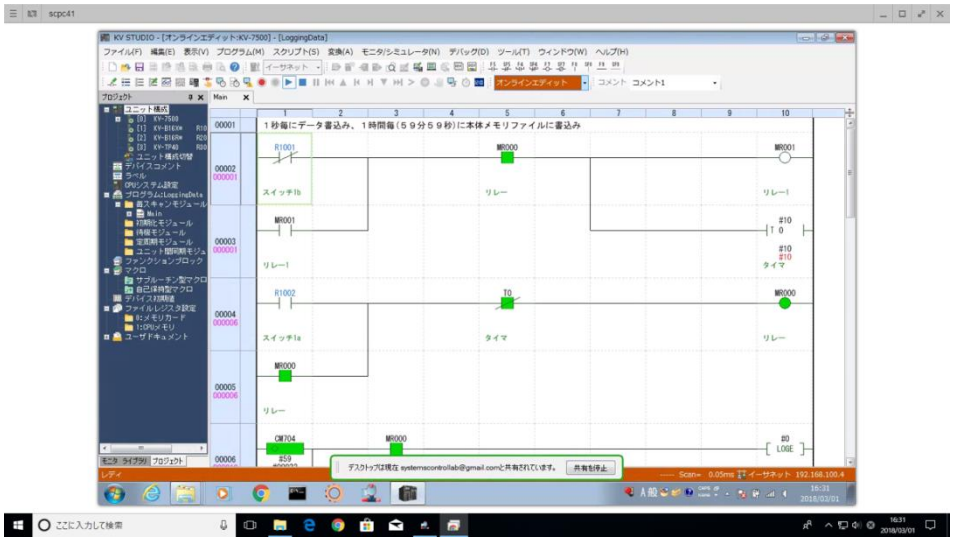


Figure 4 Screenshot of the remote operation browser (KV-STUDIO).

By using the PLC operation software (KV-STUDIO) installed in the PLC operation PC through the VPN connection, the temperature of the thermocouple was measured. The program was also used for transferring measurement data in the PLC to the PLC operation PC and extracting the real-time data from the measurement data and transferring the real-time data from the PLC operation PC to the Web server.

By using the network camera monitoring software (EasySetup) from the monitoring PC through the VPN connection, it was possible to confirm the plant images captured by the network camera as shown in Figure 5.

Figure 5 Monitoring screen of network camera.

6 Verification by Remote Monitoring and Operation Experiment

Remote monitoring experiments on the measurement values acquired from the thermocouple were conducted for the simulated remote monitoring system. Figure 6 shows a screenshot of the Web application on the monitoring PC.

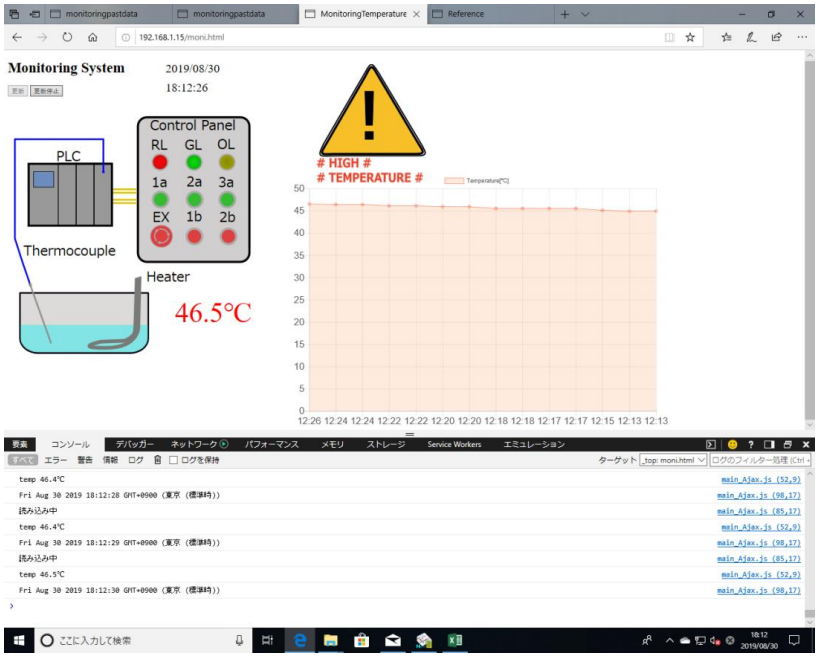


Figure 6 Screenshot of the Web browser for the experimental result.

Taking screenshots at an interval of 30 seconds from 18:10:00 based on the time displayed on the browser console (this time is the same as the time of the monitoring PC), these screenshots were displayed in the Web application. The time on the browser console, the time in the Web application and the temperature are summarized in Table 5. The time of the PLC was about 4 to 6 seconds delayed compared to the time displayed on the browser console in the monitoring PC. In the experiment, the simulated remote monitoring system realized real-time remote monitoring with a delay of several seconds from the local time.

Table 5 Time on browser console and web application and temperature of experimental result.

Browser console	Web application	Temperature
18:10:00	18:09:55	31.5 °C
18:10:30	18:10:25	34.3 °C
18:11:00	18:10:55	37.2 °C
18:11:30	18:11:25	40.1 °C
18:12:00	18:11:54	43.4 °C
18:12:30	18:12:26	46.5 °C

An experiment was conducted to display historical data from the CSV files in which the measurement values obtained by the remote monitoring experiment were recorded as accumulated data. The result is shown in Figure 7, where the date was August 30, 2019 and the display time was selected from 18:11:00 to 18:11:25, and temperature data were selected.

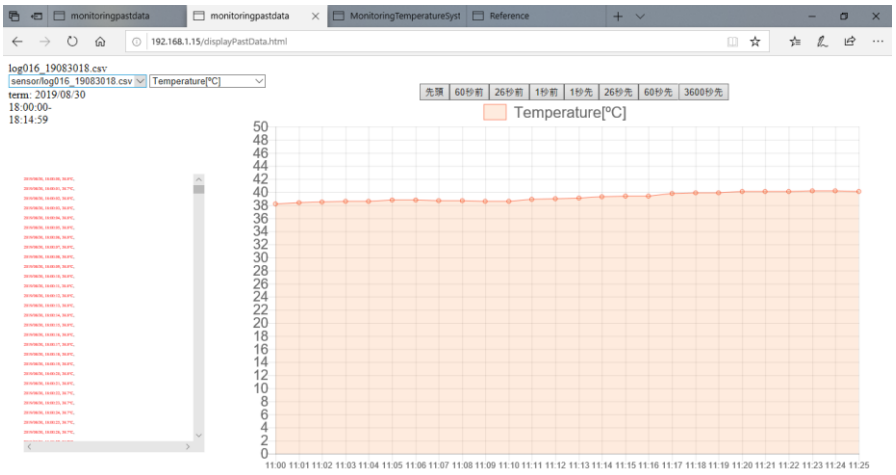


Figure 7 Experimental result for history display.

The measurement values of the temperature of the thermocouple recorded in the CSV file are shown in Figure 8. From comparison between Figure 7 and the stored data in the PLC as shown in Figure 8, the contents recorded in the accumulated data of the CSV file could be displayed in the monitoring PC.

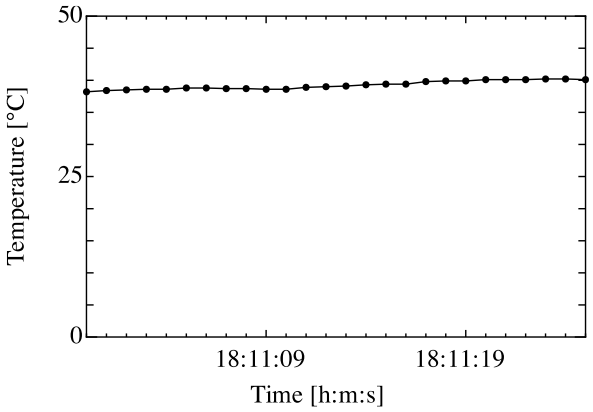


Figure 8 Stored measurement data in the PLC.

7 Discussion

In Subsection 5.4, it was confirmed that the program in the PLC operation PC could be executed by remote control from the monitoring PC. As a result, it was possible to execute the programs for monitoring the measurement values of the sensors by remote control from the monitoring PC.

As seen in Subsection 6.1, it was possible to monitor the contents recorded in CSV files. When the temperature reached an abnormal value, a warning mark was displayed in the Web browser, the red lamp on the control panel of the configuration diagram lighted up, and an alarm sounded. The state of the network camera image at that time is shown in Figure 5. This confirms that monitoring by the network camera worked as designed.

From a comparison between Figures 7 and 8 in Subsection 6.2, the contents recorded in the accumulated data in the CSV file could be displayed on the Web browser screen of the monitoring PC.

The power consumption of the Raspberry Pi (12.5 [W]) was about 1/20 of that of a common PC server (240 [W]) on a power supply basis, and the power was only 6.2 [%] of the total power consumption of the simulated remote monitoring and

operation system (202.8 [W]). On the other hand, the power consumption of the PC server (240 [W]) was higher than the total power consumption. In a remote monitoring system using a PC server with an unstable power supply, in fact, the PC server could fail due to frequent unexpected and prolonged power outages, even if an uninterruptible power supply for power outages is prepared. The proposed remote monitoring and operation system using the Raspberry Pi can be useful under unstable power supply because it can reduce power consumption drastically. Moreover, even if the Raspberry Pi breaks down due to a power outage, a replacement machine can be prepared in advance because the Raspberry Pi is cheaper compared to a PC server.

The proposed remote monitoring system was evaluated by comparing the Raspberry Pi to a common PC server. The power consumption of the Raspberry Pi was much better than that of the PC server. The amount of data to be monitored could be handled by changing the configuration of the server according to the amount of data required for the PC server, while the Raspberry Pi was limited by the fact that its storage system is a microSD card (the current system used an 8-GB microSD card).

The contribution of the proposed system can be summarized as follows: the data to be published are made available via the Internet and users can easily access the data via a Web browser. The public data can be used to monitor the status of the plant in real time. On the Web browser, the public data are displayed in a schematic diagram of the plant and the data are automatically updated in real time without any operation. Historical data can also be displayed in the Web browser.

On the other hand, with access via VPN, the operator can perform supervision, monitoring and control from the monitoring site just as if he was in the plant. It was designed so that the PLC that controls the plant can be operated completely by the PLC operation PC connected to the LAN, and the programming, operation and execution of the functions of the PLC are controlled by the PLC operation PC. Therefore, the PLC can be fully operated from the monitoring PC in the monitoring site via VPN. This is because the PLC and the PLC operation PC are connected via a LAN through EtherNET/IP.

In addition, the video from the network camera can also be monitored at the monitoring site through the VPN connection. With the network cameras properly arranged, all operations in the plant can be seen at the monitoring site as if being in the plant through the VPN connection. Furthermore, by adopting a Raspberry Pi, a low-cost and low-power consuming single-board computer, as the Web server, remote monitoring and operation for plants can be realized in developing

countries where the power supply is unstable. The proposed remote monitoring and operating system has advantages for the development of renewable energy in developing countries because it is difficult to station skilled operators in remote areas.

8 Conclusions

In this paper, a remote monitoring and operation system using both the Internet and VPN was proposed. Measurement data such as the temperature of the equipment in the plant from sensors can be displayed in a Web browser on the monitoring PC through the Internet. The PLC for controlling the equipment and network camera for capturing plant images are operated from the monitoring PC through a VPN connection. In order to evaluate the constructed remote monitoring system, water temperature measurement of a water tank in a simulated plant was constructed.

The experiment with the constructed remote monitoring system of the simulated plant confirmed that all functions worked well. In the future, the proposed remote monitoring and operation system will be verified under unstable power supply conditions and applied to various innovative energy systems, such as efficient conversion of bio-wastes to electricity by fuel cell and advanced hybrid ocean thermal energy conversion, developed in the Science and Technology Research Partnership for Sustainable Development Program.

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