Development of Distributed Plant Monitoring and Diagnosis System at Monju

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In a nuclear plant, it is required to detect an anomaly as early as possible and to inhibit adverse consequences. This requirement is especially important for a prototype Fast Breeder Reactor Monju. Therefore, a monitoring and diagnosis system is required to be developed for Monju plant equipments. In these days, such a monitoring and diagnosis system can be realized using Web technology with rationalized system resources due to the remarkable progress of computer network technology. Then, we developed a Web based platform for the monitoring and diagnosis system of Monju.

Distributed architecture, standardization and highly flexible system structure have been taken account of in the development.

This newly developed platform and prototype monitoring and diagnosis systems have been validated. Prototype monitoring and diagnosis systems on the platform acquire Monju plant data and display the data on client computers using Monju intranet with acceptable delay times. The prototype monitoring and diagnosis systems for Monju have been developed on the platform and the whole system has been validated.

KEYWORDS: FBR, Monju, Monitoring System, Diagnosis System, Distributed System, Web

I. Introduction

In a nuclear plant, it is required to detect an anomaly as early as possible and to inhibit adverse consequences. Therefore, computational operation support systems have been developed extensively for light water reactors. Japan Nuclear Cycle Development Institute (JNC) has conducted research activities on several types of plant monitoring and diagnosis techniques for Fast Breeder Reactor. Especially because Monju is a prototype reactor, a plant monitoring and diagnosis system has been developed to assure safe and stable plant operation.

This system is named dMOni (Distributed Monju Monitoring System) which consists of a data acquisition subsystem, a diagnosis subsystem, an output subsystem and a local area network (LAN). The system configuration of the dMOni is shown in Fig. 1. The dMOni displays real time data, recorded past data and the diagnostic results. These information can be accessed not only from plant operators in the main control room but also from engineers of research and development section, maintenance section and radiation control section in their own office rooms.

In this report, background and outline of system development and the application results to Monju are discussed.

II. Background

1. The operation support of the plant

Necessary information for the plant operation, such as plant state and anomaly symptoms are required to be informed to plant operators to ensure the safe and stable operation of nuclear plants. In addition, it is advantageous if plant engineers (without operators) can always monitor the plant state in their office to grasp appropriately the present plant state. Frequent monitoring of the systems and the equipments by engineers would enable early detection and recognition of failures and anomalies in the systems and the equipments.

The dMOni is not a substitution but a reinforcement of the existing monitoring/diagnosis system in the central control room. Plant operators are supposed to watch the plant state using the existing consoles in the central control room as before. The dMOni's major purpose is to support maintenance staffs in detecting incipient anomalies and degradations of an equipment or a system before plant alarm initiations. And a new diagnosis and monitoring method is tuned and validated using the dMOni, before the new method are adopted in control room's consoles.

In anomaly diagnosis, to try a new diagnosis algorithm and to make adjustments to algorithm parameters using day-by-day plant operation data and experiences are required in order to improve diagnostic accuracy. Therefore, this diagnosis system should have flexibility to allow replacements and additions of the diagnosis algorithms. This flexibility is especially desired for such a research and development phase reactor because of many needs for the plant diagnosis.

2. The targets of amorally diagnosis

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A purpose of the plant monitoring and diagnosis system is early symptom detection of anomalies and failures in the equipments and systems. The target incidents which should be detected in early stage are anomalies of systems and equipments, erroneous operations, failures of instrument and control systems. The plant state is desired to be perspicuously presented on an operation support system.

III. Development of Distributed Plant Monitoring and Diagnosis System

1. Policy of System development

Based on the background stated in Section II, the following policies have been considered in the system development.

(1) Distributed architecture

The dMOni is supposed to be used in various locations inside and outside facility buildings. And it is not desirable if one overloaded calculation module may lead to disruptions of the entire system. Also various diagnosis algorithms and monitoring functions must be added and alternated in the dMOni easily. These are the reasons why the dMOni employs distributed architectures, not only in hardwares, such as a data acquisition part, servers of diagnosis part and clients, but also in software which realize diagnostic algorithms.

(2) Standardization

In order to reduce the system development cost, the general-purpose computers and software are used. Widely available Windows machines are used as the hardware, with an option to use an existing work station. Nowadays it is nothing special to use an ordinary personal computer with an installed web browser, because the internet is becoming increasingly popular. So a web browser is selected as display software in the dMOni. Also the dMOni has some interfaces with multiple computer languages such as JAVA, C or FORTRAN so that existing or future diverse diagnosis programs can be installed easily.

(3) Highly flexible System structure

Monju is the prototype Fast Breeder Reactor in development phase, so operating experiences, maintenance experiences and accurate information of plant characteristic are to be acquired in start-up tests and in normal operation. The dMOni has a very flexible system structure in order to reflect this acquired information.

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![System configuration of dMOni](image1)

![Data acquisition subsystem](image2)
The outline of the dMOni platform

The dMOni platform is described below. These subsystems are agent-based modules placed on a LAN environment installed in Monju, and mutually communicate using internet technology.

(1) Data acquisition subsystem

Fig. 2 shows the data acquisition subsystem. The dMOni has on-line and off-line data acquisition subsystems. The on-line data acquisition subsystem of the dMOni obtains real-time Monju plant parameters (temperature, flow rate, pressure etc.) by accessing an existing plant data acquisition system: MIDAS (Monju Integrated Data Acquisition System), then delivers them to the other servers (agents).

On the other hand, the off-line data acquisition subsystem acquires field measurement data picked up by patrolling staffs through PDAs (Personal Digital Assistance). An operator inputs his/her readings into a PDA and that PDA identifies target equipments by recognizing a bar code on it. After each patrol, the acquired data by the PDA are once sent to patrol data server and then delivered to the other servers.

In addition, the past plant parameters and simulated plant behaviors are utilized in order to validate the adopted diagnosis and monitoring methods.

(2) Monitoring/Diagnosis subsystem

A monitoring/diagnosis (in Fig. 3) subsystem is the major subsystem of the dMOni and modularized into diagnosis/monitoring agents for every equipments and monitoring/diagnosis methods in order to facilitate additions and alternations of monitoring/diagnosis methods. The individual monitoring/diagnosis agents monitor/diagnose each target equipment based on acquired plant data from the data acquisition subsystem with each adopted algorithm, and share the monitoring/diagnosis results through the output subsystem to lead to an overall plant state recognition. This subsystem is mainly written in JAVA™, equipped with software interfaces with diagnosis algorithms written in FORTRAN, C, and MATLAB™ (a language for technical computing).

(3) Output Subsystem

The output subsystem displays plant data and diagnostic results on each user's personal computer and PDA using a standard Web browser. Any personal computer at any location can display plant data and diagnostic results if it is connected with the Monju intranet. PDAs can be used as the dMOni terminals at any location inside the Monju site, because the output subsystem and PDAs communicate through Personal Handy Phone System in Monju Plant. The dMOni has a function to inform diagnostic results to users using E-mail. Users are required to register target equipments, threshold values of plant data and criteria for diagnosis through the WEB browser in advance. When a plant parameter exceeds threshold values or an anomaly criterion is met, this subsystem sends E-mails to registered users.

(4) Communication subsystem

The dMOni servers communicate to each others on the Monju intranet. ECJ™ is adopted as the JAVA-based middleware for inter-agent network communication program.

Moreover, only client computers in MONJU intranet can access the dMOni, an access from internet is not considered.

3. The dMOni System

(1) Plant monitoring system, (2) Sodium inventory diagnosis system, (3) Mahalanobis Distance diagnosis system and (4) Personal alarm system are developed and validated on the dMOni platform consisting data acquisition subsystem, monitoring/diagnosis subsystem and output subsystem. The system configuration of these systems and the dMOni platform is shown in Fig.4.

(1) Plant monitoring system

Plant monitoring system presents the principal Monju plant parameters in real time with a user-friendly GUI (Graphical User Interface) display based on a plant system diagram, which draws attention by reddening the window background when a plant parameter exceeds the preset threshold. As shown in Fig.5, the GUIs display a temperature, flow rate, pressure in the secondary heat transport system and neutron flux value in the reactor core of Monju plant. The plant monitoring system can handle multiple GUIs, which enables a user to click plant data icons to get the trend graphs displayed.

(2) Sodium inventory diagnosis system

A sodium inventory monitoring system has been developed based on mass-balance calculation and now in a trial stage. In this system, mass preservation of sodium inventory is judged using sodium temperature and sodium tank level to take account of the temperature dependency of sodium density in calculating the sodium mass from the
measured tank level, in order to detect inventory decrease caused by a sodium leak.

A diagnosis target is Monju primary and secondary heat transport system. The system schematic and diagnosis algorithm are shown in Fig.6. The diagnosis algorithm is coded in FORTRAN language and connected with diagnosis agent through the FORTRAN interface in the dMOni platform. Conventional way to develop such a system requires preparation of data acquisition and display modules. However this system has been made executable only by describing a diagnosis algorithm on the dMOni platform.

(3) Mahalanobis-Distance diagnosis system
A MONJU feed water diagnosis system using a Mahalanobis-Distance is developed on the dMOni. The Mahalanobis-Distance diagnosis is described below.

Multidimensional data $X_{ij}$ on $k$ variables in $n$ samplings are collected in normal plant state. A normalized multidimensional vector $V_j$ is calculated using an average $m_i$ and a standard deviation $\sigma_i$ for $X_i$.

$$x_{ij} = \frac{X_{ij} - m_i}{\sigma_i} \quad (i=1,2,\ldots k, \quad j=1,2,\ldots n)$$

$$V_j = (x_{j1}, x_{j2}, \ldots, x_{jn})^T \quad (j=1,2,\ldots n)$$
A correlation coefficient matrix $R$ for $x_{ij}$ is calculated using $V_j$.

$$R = \frac{1}{n} \sum_{j=1}^{n} V_j V_j^T$$

The equation for the Mahalanobis-Distance $D_m^2$ is given by

$$D_m^2 = \frac{V_m^T \cdot R^{-1} \cdot V_m}{k}$$

Where $V_m$ is the normalized plant data, $R^{-1}$ is the inverse of the correlation coefficient matrix $R$.

A diagnostic target is the feedwater flow of the steam/water system in MONJU. The plant data for this diagnosis are the feedwater flow (A, B, C loop), the feedwater pump outlet head pressure and water/steam separator outlet pressure (A, B, C loop). The steam/water system schematic is shown in Fig.7. As mentioned above, the inverse of the correlation coefficient matrix is calculated using the plant data of verified normality and the Mahalanobis Distance is calculated using the inverse matrix and plant data that should be diagnosed. This Mahalanobis-Distance system is validated using MONJU startup test data that were collected when -5% step signal was impressed to the feedwater controller. The feedwater flow and the Mahalanobis-Distance before and after impression of the step signal are shown in Fig.8. The feedwater flow fluctuates slightly, so it is difficult to detect a change of the flow only by observation of a value. On the other hand, the Mahalanobis-Distance increases significantly.
as soon as the step signal is impressed, that is, an occurrence of anomaly. It is easy to detect a minute change of the flow. By using the Mahalanobis-Distance, anomaly detection is possible at an early time.

(4) Personal Alarm System

A Personal Alarm System sends an E-mail to users when plant parameter exceeds a preset threshold. This system differs from the plant monitoring system in that each user is able to set individual thresholds and to get announced of diagnosis results by E-mail. Fig.9 shows the GUI to enable a user to set a threshold and a sample of announcing E-mail. This system enables the users to detect individually interested anomalies in incipient stages before the plant installation alarm is raised.

4. Validation of system development policy

The system development policy described in section 1 has been validated for each system on the dMOni.

(1) Distributed architecture

In the dMOni, the data acquisition subsystem, the diagnosis subsystem, and the output subsystem are distributed with dedicated hard-wares, to avoid CPU load concentration. And because the diagnosis algorithms are coded as independent agents, it is possible that tasks in a subsystem are distributed to multiple agents.

(2) Standardization

Because a widely available WEB browser is selected as the display software of the dMOni, EWS, PC and PDA are able to be used as display hardware for the plant monitoring/diagnosis system. The dMOni has the software interface for multiple computing languages, selection of software developing language is not limited and existing algorithms can be utilized effectively.

(3) Highly flexible system structure

Because a software of each process is coded as an independent agent as described in (1), agents can be alternated without impacting on the other part of the system. Thus the system structure of the dMOni is highly flexible.

(4) Time delay

In general, communication delays cause problems in computer network systems, like the dMOni system on an Ethernet. As the resulting communication delay of the dMOni, it takes about 10 seconds from the time when a plant data is obtained in the data acquisition computer to the time when the plant data is displayed on output computer's WEB browser in the Monju site. Assuming that a plant engineer is using this system without a plant operator in a control room, this range of time delay is acceptable in practical use. We expect that this time delay is going to be improved because computer and network hardware ability is increasing nowadays.

IV. Conclusion

The distributed plant monitoring and diagnosis system for Monju has been developed and the system basic functions are validated. This software with distributed agents has a
monitoring/diagnosis subsystem with an interface for multiple computer languages in order to allow easy additions and alternations of the diagnosis algorithm. A Monju plant monitoring and diagnosis system has been developed at a low cost using this dMO ni platform, so that plant data and results of monitoring/diagnosis can be displayed to a large number of engineers. To contribute to a safe and stable operation of Monju, the development of the dMO ni and diagnosis algorithm keeps to be carried on.

References