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Conceptual Design of a Remote Monitoring and Control System for Nuclear Power Plants

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Abstract

Nuclear power plants (NPPs) will be highly connected network enabled systems in the future. Using the network and web enabled tools, NPPs will be remotely monitored by operators at any time from any place connected to the network via a general web browser. However, there will be two major issues associated with this implementation. The first is the security issue. Only the authorized persons need to be allowed to access the plant since NPP is a safety-critical system. However, the web technology is open to the public. The second is the network disturbance issue. If operators can not access the plant due to network disturbances, the plant will come into the out-of-control situation. Therefore, in this work, we performed a conceptual design of a web-based remote monitoring and control system (RMCS) considering these issues.

Key Words : remote control, remote monitoring

1. Introduction

Newer generation nuclear power plants (NPPs) will take advantage of more automation in operation and maintenance, fewer operators, digital technology, and advanced computer and software technology. It is likely that faster and more powerful computer processors and display technologies will allow better and more reliable control and operational strategies. The international use of computing and networking at nuclear power plants will only grow: increasing use of computer applications and displays seems inevitable simply because they have been adopted by virtually every other industry that is associated with the nuclear industry. At the same time, faster and more secure computer networks will allow better collaboration between human experts and software applications. This increased bandwidth and security will come about because government and industry demand it.

NPPs will be highly connected network enabled systems and will need to be monitored and controlled round the clock for high safety and availability. With the advance in information technology, NPPs will be monitored and controlled remotely and in real time over the internet. Today, computer network is not only fashionable, but it is easily accessible for many applications. It allows people from great distances to communicate and share information through a simple and easy means [1][2][3]. In the engineering field, network can be utilized for the development of remote monitoring and control system. Network-based systems provide the advantages as follows:

- The operator can control the system by the same interface from any places connected to the network without constructing specific infrastructures for communication.
- The system can utilize skills of operators, who are in a distant place.
- The operator is able to communicate with other operators through systems physical interaction
- The operator can use many resources which are connected to the network.

NPP monitoring systems which monitor plant status in real time using network are already implemented in some NPPs. It can only show however plant status and important variables to the people who use web browser connected to the network. In this work, we add operation functions to that. The developed system can not only monitor but also control plants. It provides the advantages as follows:

- The operator can control the system with the same interface from any places connected to the network without constructing specific infrastructures for communication and he/she can communicate with other operators, through system' s physical interaction.
- The system can utilize skills of operators who are in a distant place.

It will however have some problems. Security and network disturbance problems are the most important problems for the remote monitoring and control system (RMCS) for NPPs. The developed system does not solve all of these problems. By using intranet, the network security problem could only be somewhat solved.

2. Architecture of Remote Monitoring and Control System (RMCS)

The web-based RMCS is a four tier system, as shown in Fig 1, which consists of four subsystems. The subsystems are as follows:

- Client
- Database Server
- Control Server
- Web Server

Web server manages the communication among database server, control server, and clients. Clients can monitor and control the plant on the web using this web server. Control server delivers control requests from clients to the plant. Database server manages all data of the NPP. Usually, server-client system is a two tier system. In this work, however, we divide the server into three subservers according to their functions.

The advantages which are obtained using the four tier server-client system are as follows:

- Improvement of system stability: Because this system decentralizes loads into three servers, the system stability can be improved.
- Reduction of network traffic: This system prevents that network traffic from being driven into one server. Therefore, network traffic of each system will be reduced and the probability of network accident will be reduced.
- Improvement of security: Since the control server blocks direct connection from clients to the plant, the security of system can be improved.

2.1. Web Server

Main function of the web server is to manage the communication between clients and RMCS. In

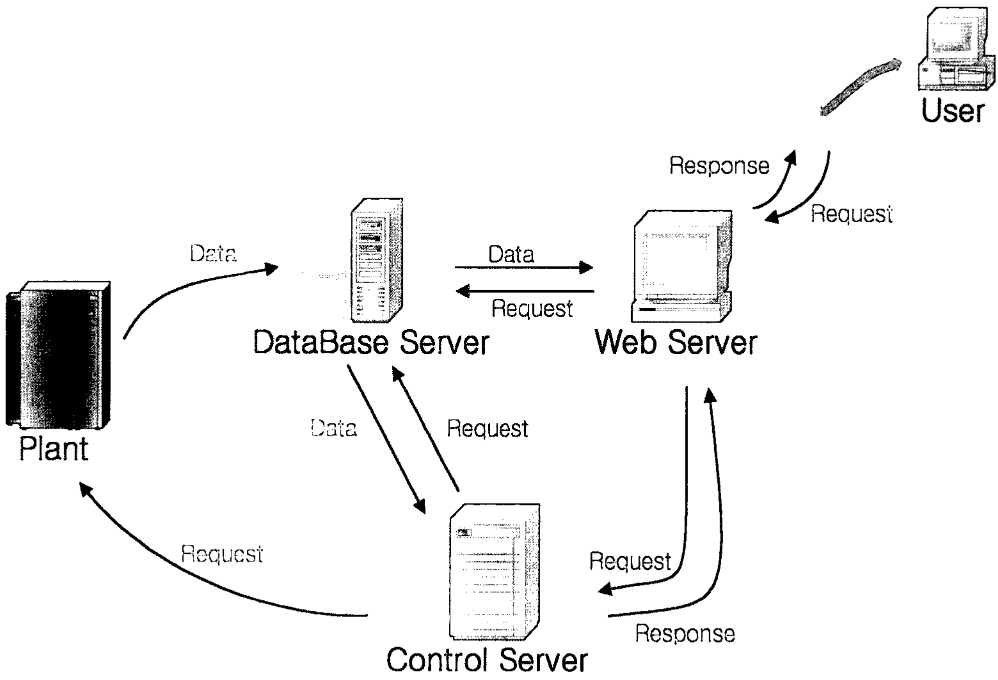

Fig.1. The Architecture of RMCS

order to provide the information required by clients, the web server is connected to the database server. It is also connected to the control server so as to transfer control signal from clients to the plant. The web server should meet the following requirements:

- The web server displays the real time data of plant requested by clients.
- The web server transfers control signals from clients to control server in real time.
- The web server has an efficient graphic user interface.

The web server has basic features as follows:

2.1.1. Log In

The clients of the RMCS are divided into three classes for security. Then, the access is limited according to the classes. The classes are as follows:

- Administrator: read, delete, update and backup data
- Registered user: read all data
- Guest: read public data, log-in not needed

2.1.2. Monitoring Function

Connected to the data server, the web server shows the current state of the plant to clients in real time. The web server has monitoring functions as follows:

- The web server shows the current information requested by clients.
  - · as systems, or as functions
  - · indicator, alarm, and status window
  - · by text or graph
- The web server shows the trend graph of specific data.
- The web server shows updated time of the data
- This function prevents clients from misbelieving current data as the latest when a network

accident happens.
- The web server controls the amount of information provided for clients.
- The web browser has spatial limitation. Therefore, the web server should provide the essential information with which clients can recognize the state of the plant.

2.1.3. Control Function

The web server delivers the control signal from clients to the control sever.
- control icon
  - on/off control, analog control, and digital control
- control support
  - confirmation and validation of the control signals
- to check that a control signal is correctly transferred to the control server

2.1.4. Intelligent User Support

It may be difficult for web clients to identity correctly the state of the plant because the clients should monitor and control the plant through the web. Therefore, the functions to support the clients are necessary. The functions are as follows:
- to diagnose abnormal state and suggest appropriate procedure
- to validate the control signals from clients
- the take over between automation and manual operation

2.2. Database Server

In RMCS, database server has the following five requirements:

1) Data management: First, Database must minimize its loss of data while maximizing its integrity. If the same data duplicate, space is wasted and the efficiency of database decreases. The discord of data diminishes the reliability of the database. Secondly, the data storage process must be simple. If the process is not simple, overhead occurs when the data stored and the efficiency of system is decreased.
2) Real time extraction of plant data: The data which users demand must be transmitted fast to the users.
3) Security level management: Each user must have different permissions when accessing the database. If all users are able to change the data stored in the database freely, the data stored in the database would not be reliable. Furthermore, if someone who is not allowed succeeds in corrupting the database, the stability of whole system would be lost.
4) Transfer of the requested data to web server: The user connects to the web page and requests data. Therefore the database must be able to link with web server.
5) Data backup: Data backup is necessary to protect the data from unexpected situations that could lead to the data loss or damage.

In this work, the FISA-2/WS simulator is used in place of a real NPP for developing the prototype of RMCS. FISA-2/WS is based on KORI unit 2 and was developed in 1992, and it can simulate various accidents such as LOCA, SGTR, and so on. There are 188 variables in FISA-2/WS simulator. These variables can be classified into several different groups. The groups are as follows:

1) Classification variable type - Some variables are classified into monitoring variables that can express conditions of NPP. Some of the others are classified into control variables that can control NPP.
2) Classification plant system - The variables of plant simulator also can be classified into plant system. Except for the above classifications,

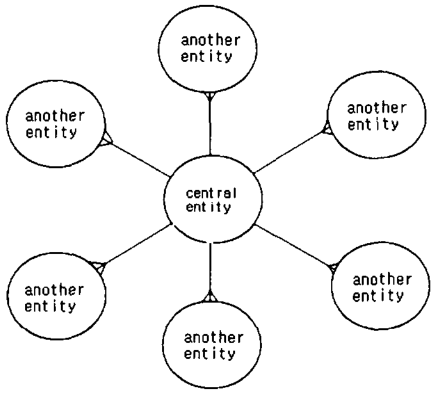

Fig. 2. The Radial Relation

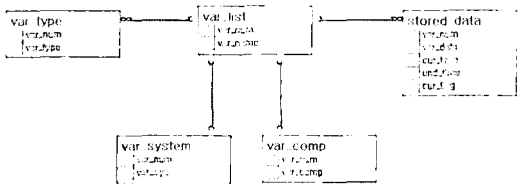

Fig. 3. ERD of the Database Using Relational Database in RMCS

there can be more classifications. For example, if it is a requirement that the user be able to categorize the variables by the functions of a plant system available to the power plant during remote administration, then the variables must be categorized by the function of a plant system and added to an entity relation diagram (ERD) beforehand.

A new type of data model is introduced in this work. The name of the data model is 'radial relation' , which is developed in this work and shown in Fig 2. 'Radial relation' means that relations among the entities have radial structure. All entities except for the central entity have the relation with the central entity only. Since each entity is independent from one another, inserting new entities or deleting existing entities can be done with ease. The structure of the radial relation is so intuitive that the developer can easily grasp the whole structure of the database. In conclusion, the database using the radial relation can be easily repaired, maintained and expanded. Since each entity is separated independently, user can use only the entities which are needed. Therefore the size of a table can be minimized with using radial relation. On that score, the database that uses radial relation is faster than the database which has all attributes in one table.

Table 1. Cooling Rate During the DHC Tests in Water and Air

string	number of data to be searched	response time of relational database (ms)	radial response time of the other database (ms)
cur_flag=1	11	15.10	15.40
cur_flag=0	81390	107.42	167.66
var_flag=1	7410	210.89	279.80
var_comp=SG	44401	1287.24	1389.19
var_num=1 and cur_time =' 00:00:00' and '01:00:00'	720	21.50	28.46
var_num=1 and cur_time=' 00:00:00' and '05:00:00'	3600	63.50	98.47

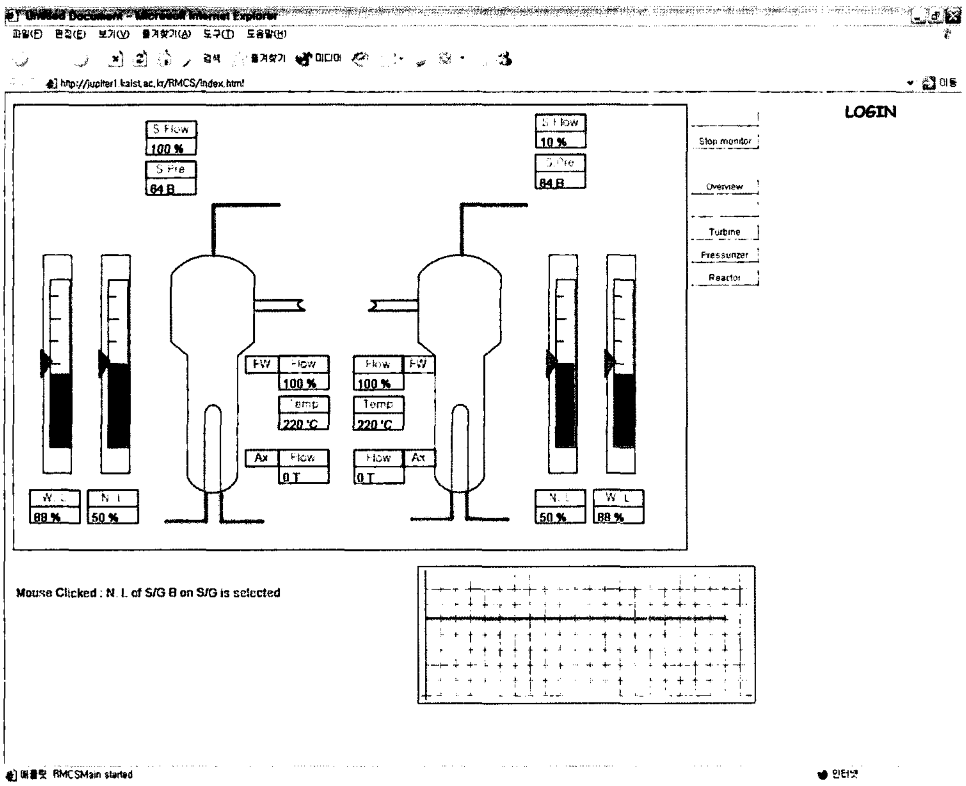

Fig. 4. Prototype of RMCS

An example of an ERD is shown in Fig 3. The ERD that uses radial relation would be used at database in RMCS. In Figure 3, each entity has several attributes. Of course, thanks to the radial relation, the developer can insert a new entity or delete an existing entity at any time. Even after the development of the database is completed, amendment of the database is possible.

In order to validate the efficiency of database, a test is performed by comparing response time of a database that uses radial relation with a database in which all attribute are inserted into one table. The response time is measured by searching the data for several different strings and the times are recorded. As shown in Table 1, the search time for the database that uses radial relation is shorter than that for the other database. It is shown that, in cases where the number of searched data is small, the difference in the response time was not large. However in cases where the number of the searched data is large, the difference widens.

As the number of searched data increases, so does the efficiency of the database.

2.3. Control Server

There are some issues in a network-based system such as a security issue, a network disturbance issue, a real-time performance issue and so on. Therefore we designed the control server in order to cope with these issues. The control server plays a role of an agent between the web server and a plant. Users must be connected with a plant through the control server, and the control server can remove unsuitable control requests for a current situation of a plant. The function which is able to validate control requests of users can reduce problems caused by the security issue, but the function was not designed in this work.

Among the issues of network-based system, a network disturbance issue is the most serious issue. In this work, we made a priority designing of a function against network disturbances. Network disturbances can isolate human operators in remote places from NPP. In network disturbances, local operators must manage the NPP. However, if some accidents isolate human operators in local as well as in remote area from NPP, there will be no one who can manage the plant and it can cause serious accidents. Therefore, we needed to develop a system to cope with these emergency situations, and we developed the automated operating procedure system (ATOPS) [5] [6].

ATOPS envisioned is an automated operating system with the additional ability to aid operators performing procedures. ATOPS is a kind of automation system that operates a machine system according to prescribed procedures without any human operators' help. Operators in the main control rooms (MCR) of NPPs monitor signals diagnose current status and perform suitable actions according to corresponding operating procedures. ATOPS performs actions as MCR operators do: it monitors the plant status, detects anomalies, diagnoses the status, and performs control actions on the plant according to corresponding operating procedures in order to maintain the plant in a stable state when the emergency situations such as network failures occur without any support of both local and remote operators. If some accidents isolate human operators in local as well as in remote area from NPP, then ATOPS begins to work. In these cases, ATOPS manages NPP autonomously in order to maintain stable and safe state of the plant until the accident is recovered.

In normal and abnormal situations, human operators also handle a lot of information. Thus, even a good operator can make mistakes. ATOPS can be used for an operator support system executing autonomously simple jobs which do not need human operator' s supports in order to reduce the workload of human operators. Therefore, in the control server, ATOPS can not only be used as the automation system against emergency situations, but also as the operator support system for normal and abnormal states. Various operation processes of NPP can be executed by ATOPS and it can prevent human errors and reduce workload of operators in normal and abnormal states.

3. Conclusions

We developed a web-based RMCS that uses prevalent web technology, as shown in Fig 4. The aim of the system is to monitor and control NPPs from distant remote places using network. In this work, as a preliminary study, we performed the conceptual design of the web-based RMCS and we developed a prototype.

Since the web-based RMCS is connected to the NPP using networks, it has several issues to solve. The first is the security issue. Only the authorized persons need to be allowed to access the plant since NPP is a safety-critical system. However, the web technology is open to public. The second is the network disturbance issue. If operators can not access the plant due to network disturbances, the plant comes into an out-of-control situation. Therefore, in this work, we performed the conceptual design considering these issues.

The web-based RMCS is a four tier system which consists of four subsystems. The subsystems are as follows: client, database server, control server, and web server. The web server manages the communication among the database server, the control server, and clients. Clients can monitor and control the plant on the web using this web server. The control server delivers control requests from clients to the plant. The database server manages all data of the NPP. We implemented the database server using the radial relation database developed in this work. We also developed ATOPS using FCPN for use in the control server.

This work is a preliminary study of the RMCS and we focused on improvement of system performance and network accident management. Therefore, we designed the RMCS in four tier system, with the radial relation database, and with ATOPS. However, in order to adopt ATOPS to real plants, we need to perform more in-depth studies on advanced HMI systems and on intelligent systems. It may be difficult for operators in remote places to identity the state of the plant correctly because the operators should monitor and control the plant through the web and the web browser has spatial limitations. Therefore, the functions which help the operators to identity current plant statuses are necessary, such as alarm systems, decision support systems and efficient display functions. The web server must include these operator support systems for accurate remote operations. Also developments of intelligent systems which validate the control signals from clients are needed for the control server. These systems are to exclude wrong control requests by operators' mistakes. The researches on advanced HMIs and on intelligent systems remain for future works.

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