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Development of Open Test-bed for Autonomous Operation in Nuclear Power Plants

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1. Introduction

In the industry as a whole, the level of automation system along with the key artificial intelligence (AI) of the fourth revolution, is gradually increasing and developing. Autonomous operation and automation techniques can be equally accurate in comparison to human beings, and in the same way that they are able to accurately determine a large amount of data, and also play a key role in the military, which can replace human beings in industries with high risk levels. Autonomous operation and automation technology can accurately and quickly judge a large number of data at the same time and in comparison with humans, and it also plays an important role in high-risk industries such as the military and aerospace industries due to its ability to replace humans in high-risk industries.

Nuclear power plants also recognize the need for automation. However, it is dangerous technology to have a significant impact on human society. In addition, due to the uncertain legal responsibility for autonomous operation, the application and development speed of nuclear energy related automation technology will be significantly decrease compared to other industries. It is argued that the application of AI and automation technology to power plants should not be prematurely applied or not based on the principle of applying proven technology since nuclear power plants are the highest level security operated facilities. However, power plant instrumentation control methods such as automatic operation can be classified as low-level AI. In other cases, it is already verified that AI and automation technology show more accuracy and speed than people. [1]

Therefore, this paper deals with the contents to make autonomous operation in nuclear power plants more practical. In case of abnormal state in nuclear power plant, entry and response actions of the alarm procedure are representative cases.

This paper will introduce you to three things :

1. Determining appropriate and rapid procedure in abnormal situations.
2. Reduction of human error due to operator through cooperative semi - autonomous operation of operator and autonomous driving algorithm.
3. Development of open Test Bed, which various automation algorithms can be continuously improved and compared.

2. Methods and Results

2.1 The basic structure of Test-bed

The open type test bed is being developed because automation requires continuous data and various algorithms should be compared at the same condition. In this paper, it is being made to demonstrate the possibility of an open type test bed. The test bed basically consists of three modules: a simulation module, an interface module, and a test bed sharing platform. The simulation module calculates the thermodynamic state of the power plant using the MARS simulation code to simulate the thermal hydrodynamic state of the power plant. The interface code changes and processes the calculation results of the simulation code to make it easy to use in the test bed shared platform. Through this, even if the automation module of the test bed shared platform is changed, it is possible to link with the simulation code through modification of the interface. In the case of a test bed shared platform, the user diagnose the plant condition and evaluate the appropriate actions by applying the autonomous mode algorithm to the simulation result processed by the interface module.

The Noise modules were added between the interface module and the test bed platform. In actual power plants, measurement noise may occur due to the electrical signals of the instrument. However, since the MARS program, which is a simulation code, does not consider these things. So, add a noise module between interface module and test bed module to generate an alternative noise. [2] The preprocessing process at the condition monitoring stage of the test bed platform will make accurate judgement even with the noise mixed data. [3]

The MARS simulation code consists of a control variable, a logical trip, and a variable trip card. The control variable card represents observable and thermal hydraulic variables such as steam generator level, PCT calculation, pressurizer pressure, reactor head top head height, and so on. In the case of a variable trip, it works when the specific control variable specified by the user reaches a certain condition, thereby it will simulate the automatic action of the power plant and the operator action. Logical trips can be used to create and apply higher-order control algorithms by constructing AND gates, OR gate by using Variable trips. The MARS simulation code is able to identify and control most of the thermohydrodynamic signals that occur in the power plant. Therefore, it is possible to acquire and extract data in abnormal

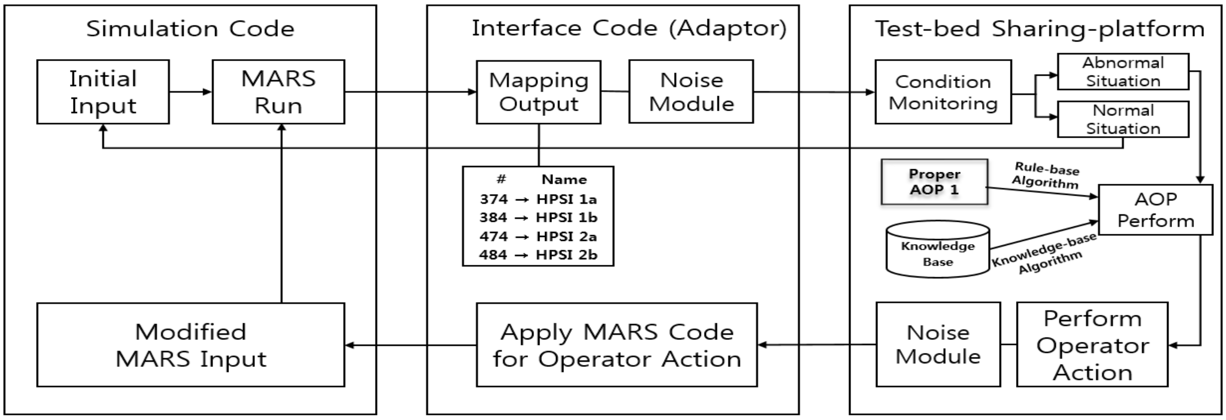

Figure 1. Schematic diagram of Test-bed

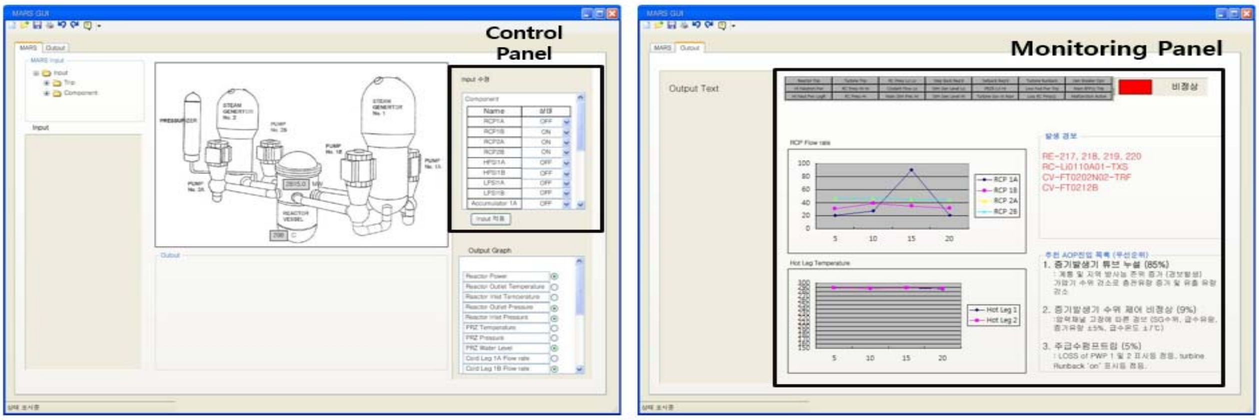

Figure 2 Basic User Interface for Test-bed

state by using MARS code, and it can be used for automation algorithm learning. In the case of a general MARS simulation, the accident inspector is applied to the input file to analyze the simulation result after the event. [4]

However, in this study, only the initial event (eg SGTR) is applied to the input file and subsequent actions are not applied. Instead, after obtaining the MARS code after the desired time, it analyzes the result and performs appropriate action when it is necessary by using the automation algorithms. Through repeated execution of these processes, the situation which the actual operator monitor the status of the power plant in real time will be simulated.

2.2 Selection of Operating procedure & Diagnosis of entering condition to Operating procedure

The first step to verify the development of the test bed is to select the operating procedure. Among the operating procedures used for nuclear power plants, the operating procedures directly linked to the safety of nuclear power plants are abnormal / alarm operating procedures and emergency operating procedures (EOP). As mentioned above, one of the various advantages of automation is that it can reduce human error, but the automation algorithm is also developed by human beings, so it can't be sure completely from human error.

Although the automation algorithm for various operating procedures has been proposed, the EOP is difficult to apply in reality due to the stability, safety and the importance of the situation. In case of abnormal operating procedure (AOP), it was judged that it would be effective because it can reduce the sudden stop. Thus, the scenarios used for building the test bed was based on AOP.

Entering to the AOP is determined by checking the corresponding alarms and symptoms in the procedure. Two errors can be occurred when decide to enter the AOP through the alarm only.

1. Unable to determine an appropriate AOP with the alarm conditions.
2. Unable to select an appropriate AOP when a large number of abnormal conditions have occurred.

In case 1, it is possible to recognize the accurate situation by judging the entrance in consideration of the main signals in addition to the alarm. It can reduce the occurrence of errors because the symptoms are already present in the AOP. However, in the case of multiple alarms in 2, it is difficult to judge the correct procedure with the alarm only in the abnormal operating procedure which is in charge of the transient situation. [5] Also, there are many heuristic part in AOP which is the portion to be judged based on the knowledge of the operator, such as 'if ~ increases,' 'if ~ is maintained,' 'when ~ is necessary'. Different conclusions are possible depending on the operator because it is not presented the accurate numerical data. There is no big problem if the operation is done well to the end, even if the judgement from the operator is not the same. If the operator fails to enter the AOP for alarms and symptoms and respond effectively, it may cause a sudden stoppage of the power plant.

To solve these problems, early warning algorithms and classification methods can be used. Based on the realization of the abnormal state, it is possible to accelerate the entry of the abnormal driving procedures, which means that the operator can have more time to response for corresponding to the situation.

In other words, when a process signal enters, it transforms (noise cancellation) through RSM (Residual Sign Matrix) and determines normal situation and abnormal situation through SVM (Support Vector Machine) which is data mining technique. [6]

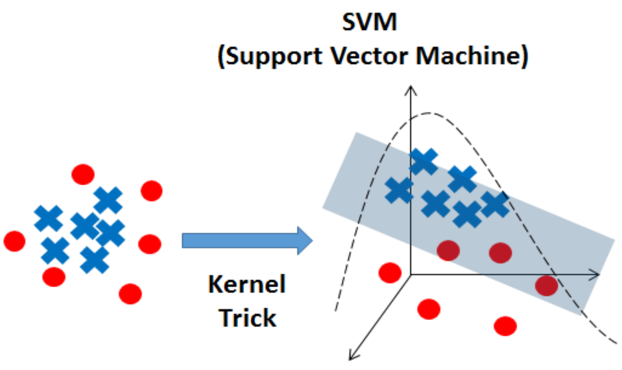

Figure 3 Principle diagram of SVM

2.3 Development & Verification of autonomous algorithm

The following mechanism after the algorithm of decision for entry to AOP is automation algorithm. Automation algorithm is categorized by three.

1. Automation algorithm through rule-based expert system
2. Automation algorithm by machine learning
3. Semi-automation algorithm

2.3.1. Rule-based expert system

The Rule-based expert system is a technique for controlling Automation by reflecting explicit driving knowledge in a situation clearly known as normal situations or abnormal situations. In this case, it is possible to operate in the "autonomous operation control" mode by inferring a rational response method to the abnormal situation by applying the rules and reasoning techniques applied in the expert system. Also, it is necessary to reflect the heuristics or tacit features that are not shown in the procedure, reflecting the actual confirmation or conversation of the operator in relation to performing the operating procedure.

2.3.2 Artificial intelligence by machine learning

The operating control that based on rule-based system recorded as cases. It can be used for classifying and controlling the normal situation and abnormal situation state. Also, it is possible to improve the continuous driving adaption and performance through the machine learning. For this, it can be applied the reinforcement learning techniques, artificial neural networks, and deep learning etc.

2.3.3 Semi-autonomous operation algorithm

Autonomous operation can also cause an error, and a typical situation where this happens is an untrained event, that is, real-time sensing data is not defined in advance. In order to prove this unknown situation, the diagnosis and change detection used in the operating procedure entry judgment are needed. Diagnostic algorithms can be used such as logistic regression, Support Vector Machine(SVM), and Mahalanobis Taguchi System(MTS) for diagnosis and change detection. If it turns out to be an unknown situation, a semi-autonomous driving algorithm will be used that either passes the operating privilege or operates in a cooperative driving control mode, providing operator action information based on past similar cases and approving it by the operator. [7]

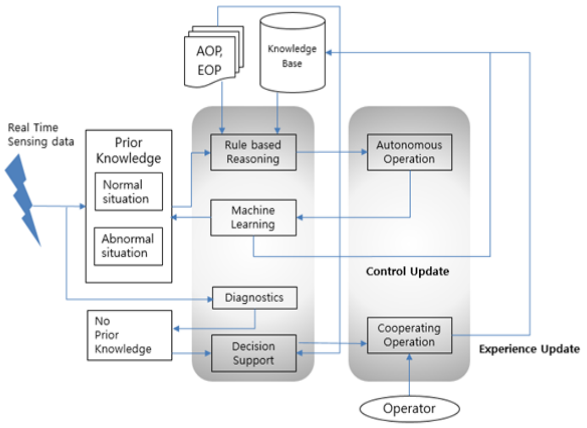

Figure 4. Schematic diagram of autonomous algorithm

3. Conclusions

As described above, the overall algorithm of the Test Bed is an autonomous operation algorithm (rule-based algorithm, learning-based algorithm, semi-autonomous operation algorithm) to judge the entry condition of the procedure through condition monitoring and to enter the appropriate operating procedure. In order to make a test bed, the investigation for the heuristic part of the existing procedures and the heuristic part from the circumstance which is not specified in the procedure is needed. Also, input coding at the time of significant change through observation of MARS program output is needed for rule-based expert system regarding with developing the autonomous algorithm. In the learning-based and semi-autonomous operation algorithms, using MARS to extract its operating data and operational logs and try out various diagnostic algorithms as described above. Through the completion of these future tasks, the test bed which can compared with actual operators will be constructed and that it will be able to check its effectiveness by improving competitively with other research teams through the characteristics of shared platform.

Acknowledgement

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