Development of an advanced operation support system

UENO Yohei, KAWAGISHI Motohiko, and OI Tadashi

Advanced Technology R&D Center, Mitsubishi Electric Co., Hyogo, Japan
(Ueno.Yohei@aj.MitsubishiElectric.co.jp, Kawagishi.Motohiko@ds.MitsubishiElectric.co.jp, Oi.Tadashi@bx.MitsubishiElectric.co.jp)

Abstract: In the main control room of a nuclear power plant, the number of pages on the operator’s console increases to hundreds due to complicated structure and monitoring task requirements. Therefore, the human-machine interface system usually provides a transition mechanism for accessing a specific page to display. A transition mechanism has been investigated that uses on-screen “transit buttons” to dynamically link to pages corresponding to the next step in the operation. This enables an operator to bring up and view appropriate monitoring pages more rapidly.

Keyword: human-machine interface, adaptive interface, operation support

1 Introduction

Advanced monitoring and control consoles are steadily replacing conventional analog consoles in the main control rooms of nuclear power plants. These advanced consoles offer good usability because they use a visual display unit (VDU) and a large display device, enabling them to display many kinds of information and control interfaces on one screen. They also have a flexible display interface. Several human-machine interface (HMI) systems have been developed for advanced consoles, including an error message system and a user guidance system. [1]

There are, however, problems with advanced consoles. One involves the operability of the display interface. For example, an enormous number of pages may be displayed on the VDU because many indicators and controllers must be displayed on the VDU as opposed to analog consoles. The operator may thus need to search for a particular page from among a large number of pages displayed on the VDU.

We have developed several prototype HMI systems and are now focusing on enhancing the usability of the interface management control function in the operation console. Here we describe our investigation of a page transition mechanism that enhances the usability of a monitoring and control display system. With this mechanism, the next operation is forecast on the basis of operation templates, plant-measured values and/or operational records, and the links of on-screen buttons are dynamically changed accordingly.

In the next section, we describe problems with the conventional display interface of advanced operation consoles and an overview of the mechanism we investigated. In section 3, we describe the operation of the mechanism. In section 4, we discuss its evaluation and planned evaluations. We conclude in section 5 with a brief summary of the key points and a look at future work.

2 Problems and overview

2.1 Problems with conventional interface

Not all plant information can be displayed on one screen of the VDU at the same time because the amount of data is enormous. Since most systems have a great number of monitoring and control display pages, the operator must frequently change the pages displayed in accordance with the current situation.

Most systems change the pages displayed by using a page search function, a menu page with a list of pages, or a transit button, which is a software switch displayed on the operator’s console that has a link to another page. When the transit button is pushed, the displayed page switches to the linked page. The links between pages are static, and each page has specific “transit buttons”.

Transit buttons are the easiest and the earliest way of changing the page. The links between pages are determined by the relationships between their contents. For example, a page with a system diagram may link

Received date: November 18, 2009
(Revised date: April 20,2010)

to a page with a summary information view, one with a detailed value view, one with a neighboring system diagram, one with the operation switch for the instrument indicated in the diagram, and a last one describing the next step in an operation sequence.

Displaying transit buttons for all the links from a particular page is difficult because of the limited page layout. If the page currently displayed does not have a link to the target page, the operator must either go through irrelevant pages until reaching one with a link to the target page or select the target page from a menu that might list hundreds of pages. If an accident occurs and an operator must perform several operations within a short period of time, having to traverse through many irrelevant pages may cause the operator to initiate an incorrect operation.

2.2 Overview

The page transition mechanism we investigated guides the operator through relevant pages on the basis of plant-measured values and/or operational records. As shown by the example display page in Fig. 1, the next operation is forecast, and the links between the current page and the pages related to that operation are assigned to the transit buttons, which are shown in gray at the lower left of Fig. 1. Therefore, the operator avoids switching to irrelevant pages and can reach the target page directly.

The target operations for this system are fixed sequential operations, such as the restore operation after an accident occurs. The operations for normal conditions are beyond the scope of this work.

3 Transition mechanism

The key steps with this mechanism are forecasting the next operation and changing the button page links dynamically.

Before the mechanism can be used, operation templates must be registered. This means registering the sequential operations described in the plant operation manuals as “operation templates”. This is described in detail in section 3.1.

These operation templates, along with plant-measured values and/or operation records, are used to estimate the current status of plant operation. This is described in detail in section 3.2.

On the basis of the template, the next step in the operation currently being performed is “forecast”.

The dynamic links assigned to the buttons are changed when the page displayed is switched. Therefore, the dynamic linking is unlikely to lead to an incorrect operation, which could easily happen if the links were changed just as the operator pushed the button.

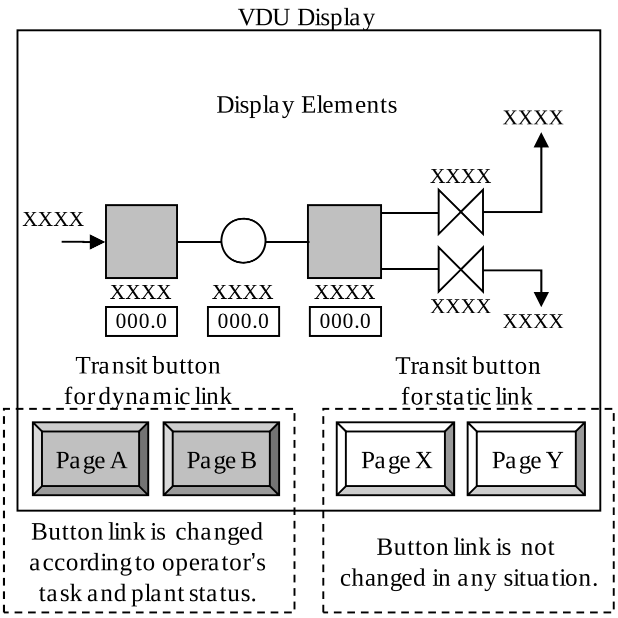

Fig. 1 Example display page.

3.1 Registration of operation templates

The plant operation manuals likely describe complicated procedures, such as parallel operations and bifurcations. In addition, operators may be called upon to perform a sequence of steps not described in the manuals, such as performing steps in a different order or switching from one sequence to another.

We simplify the operation templates and define conditional sentences for each template in order to handle such procedures.

- Simplification of operation templates

If a procedure has a bifurcation, the procedure is divided into the part before the bifurcation and the parts after the bifurcation, and each part is registered as an operation template. Therefore, the registered templates have no bifurcations. In the example shown in Fig. 2, the procedure is divided into three templates.

- Definition of conditional sentences

Several conditional sentences, such as the condition for starting the operation, are defined for each operation template. We classify these conditional sentences into three types.

1. Precondition

A precondition is a condition under which an operator is allowed to start operation of the template. Information used for preconditions includes plant-measured values, alarm information, and operational records. Each precondition has a priority index that is defined when the precondition is established.

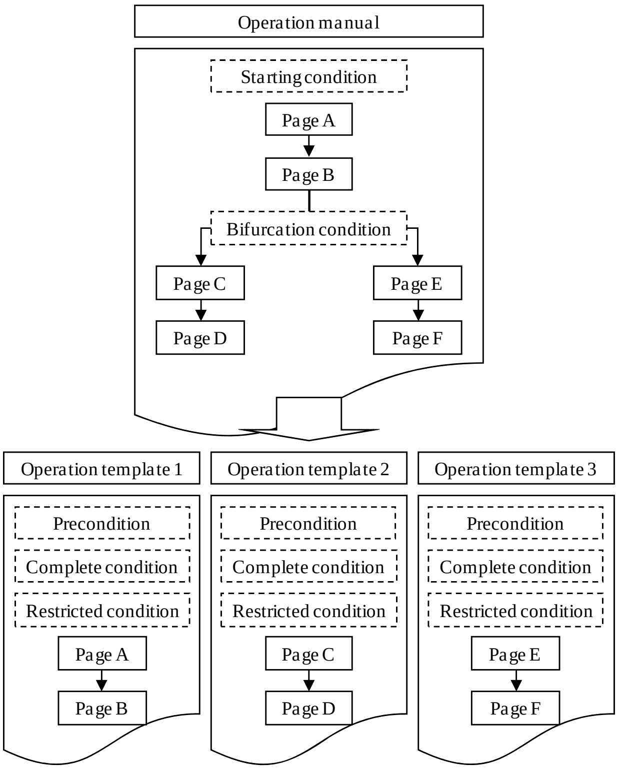

Fig. 2 Simplification of operation templates.

2. Complete condition

A complete condition is a condition under which an operator must continue the operation sequence. The operator continues to operate the template until the complete condition is satisfied.

3. Restricted condition

A restricted condition is a condition under which an operator should not perform an operation. Restricted conditions are used to prevent incorrect operations. When a restricted condition is established, the operators are cautioned about performing operation of the template.

The system can handle several types of actual operations by dividing templates. For example, templates that have the same preconditions and complete conditions may correspond to a parallel operation procedure. For another example, if there is a problem in a system loop, the restricted condition of the template for the problem loop should be equal to the precondition of the templates for the other loops. That way, an operator can restore operations while the system restricts the operation of the problem loop.

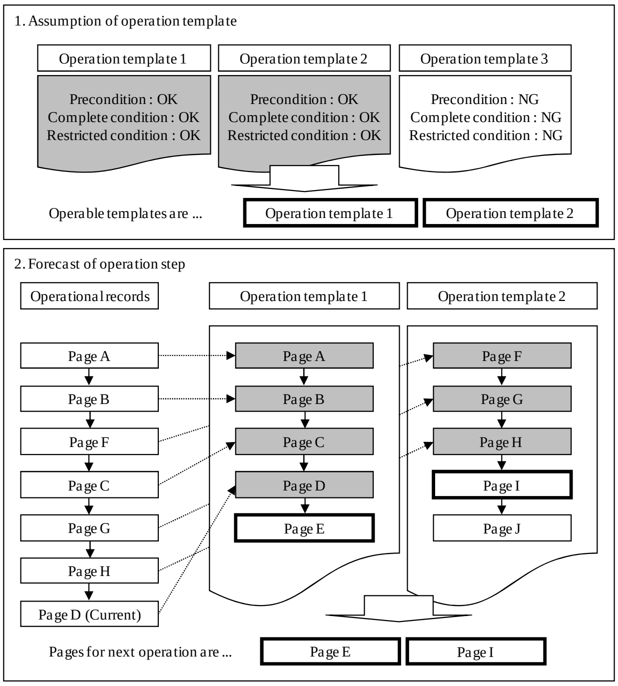

Fig. 3 Method for estimating the current status of the plant's operation.

3.2 Estimating current status of plant operation

The current status of the plant's operation is estimated in two steps, as illustrated in Fig. 3.

1. Which template matches the current operation?

The operability of a template is inferred from the preconditions, complete conditions, and restricted conditions. If a template is operable, the current status is forecast using the pattern matching method. The input data for the algorithm used are plant-measured values and operational records.

2. Which step in the template matches the current operation step?

The current operation step is identified by comparing the steps in the template with the operational record.
Once the current operation step is identified, the next step of the current operation is forecast to be the next step.

- Pattern matching

The template contents are compared with the operational records by using a difference algorithm. [2]
The O(NP) difference algorithm[3] is used to search for the longest common subsequence (LCS) or shortest edit distance (SED). Fig.4 shows an example of the edit graph and valuation for the case illustrated in Fig. 3. The gray bold line represents the optimum path.

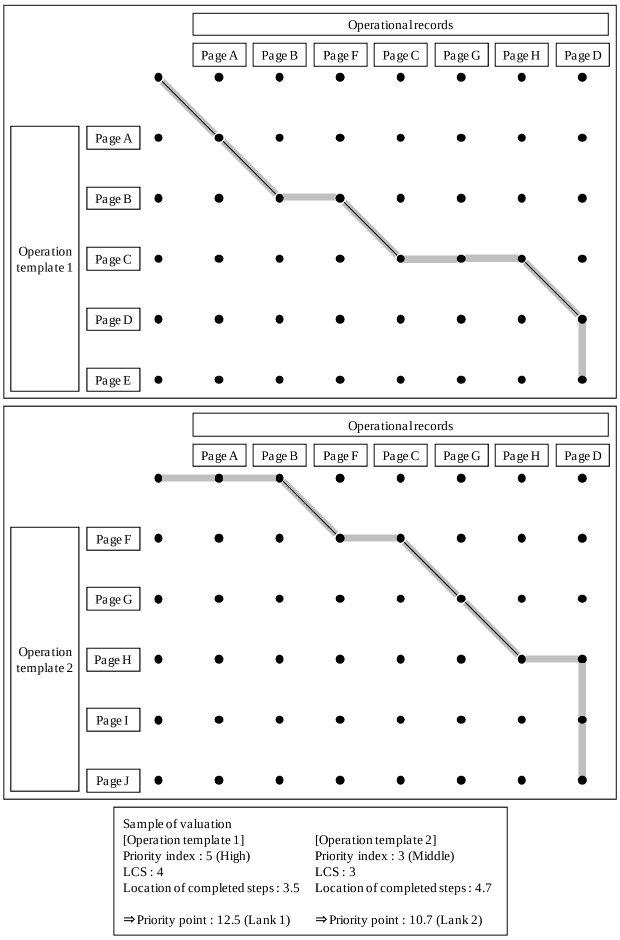

Fig. 4 Example of edit graph and valuation.

The LCS is calculated by comparing the operation template and operational record. The LCS is the same as the number of the step in the operation sequence that was last completed. The operation priority of each template is determined on the basis of the points calculated from the LCS.

- Priority index for preconditions

A template that is apparently more urgent is given a higher priority index. The template with the highest priority is performed first.

- LCS

The template with the largest number of completed steps is given a higher priority.

- Location of completed steps in operational record

The template that has been operated more recently is given a higher priority.
When registering the operation templates, it is difficult to include flexibility in the sequence of operation steps. For example, consider a sequence consisting of four steps (A, B, C, and D). The order of operation for the first three steps is not important.

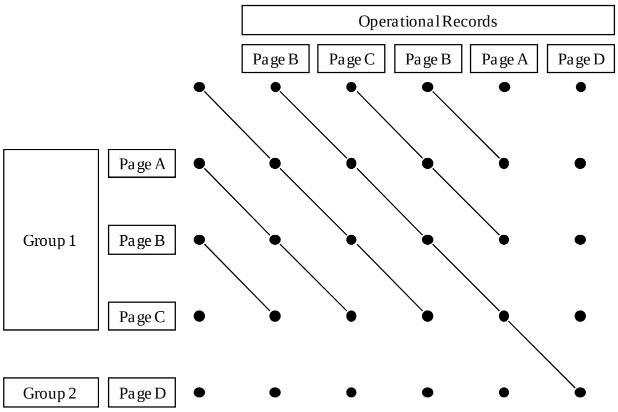

Fig. 5 Edit graph with improved method

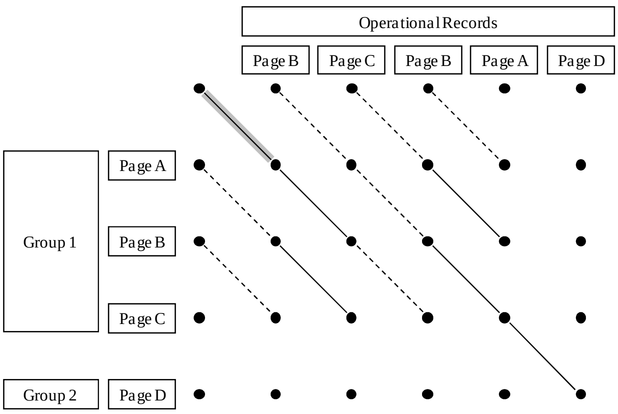

Fig. 6 Erasing of diagonal.

However, the last step should be performed only after the first three steps have been completed. This means that restricting the sequence to one pattern (e.g., Step A-Step B-Step C-Step D) is not acceptable because of the allowed flexibility in performing the first three steps. However, providing for all six possible patterns is also not acceptable because doing so would degrade the efficiency of the search algorithm.

We thus improved the difference algorithm so that it can handle the grouping of operation steps. The improved algorithm works as follows.

- Step 1.

Diagonals of the edit graph are established on the points where the operation group of the item on the x-axis is the same as the group of the item on the y-axis. (See Fig. 5)

- Step 2.

The optimum path is searched for using the O (NP) difference algorithm. If the path passes the diagonal, Step 3 is carried out.

- Step 3.

If there are the same combinations of groups and items, the diagonal is erased, Step 2 is returned to. In Fig. 6, the diagonal for the combination of group 1 and Step B (dashed lines) is erased.

Finally, the optimum path is found (Fig. 7). Even if the first three steps (i.e. Step B-Step C-[Step B]-Step A) are performed in a different order, the result is the same.

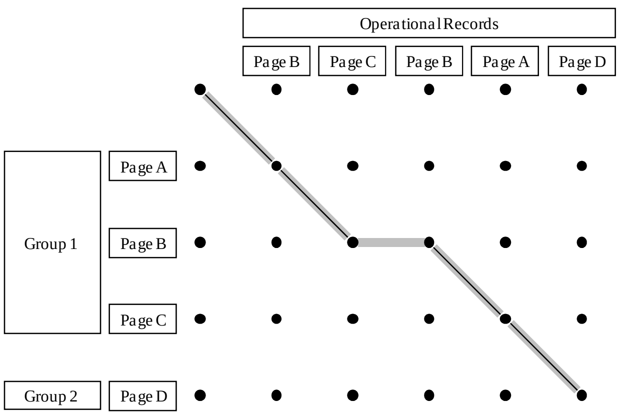

Fig. 7 Optimum path.

4 Evaluation

4.1 Precision of system guidance

We carried out a computer simulation of the method for estimating the current operation and examined the precision of the system guidance. We set the simulation data by referring to actual systems and operating sequences.

- Monitoring Pages: 27
- Operation Templates: 5

Template 1: 9 Operation Steps, 11 Irrelevant Steps
Template 2: 5 Operation Steps, 3 Irrelevant Steps
Template 3: 3 Operation Steps, 2 Irrelevant Steps
Template 4: 15 Operation Steps, 10 Irrelevant Steps
Template 5: 5 Operation Steps, 7 Irrelevant Steps

Template 4, which represents the longest operation, has 15 operation steps and 10 irrelevant steps to reach the target monitoring pages. Therefore, an operator must open at least 25 monitoring pages to complete the Template 4 operation.

We operated using each template, and verified that the correct template was found in all cases. We also counted the number of irrelevant steps avoided by using the transit buttons.

As shown in Table 1, almost all irrelevant steps were avoided for templates 2 and 4. With template 4 in particular, all 10 irrelevant steps were avoided. This demonstrates the effectiveness of not interrupting the operation sequence by viewing irrelevant pages. In contrast, with templates 3 and 5, only one irrelevant step was avoided. One explanation is that there were the same part of operation steps between templates 1 and 5 and templates 1 and 3. Therefore, the system could not determine which template to suggest.

In this simulation, we did not define conditional sentences, as described in section 3.1. Such sentences would have been useful in these cases. Another approach to solving this problem is to display all the templates regarded as high priority and let the operator select the one to use.

Table 1 Results of the evaluation

	Avoided Steps
Template 1	5
Template 2	5
Template 3	1
Template 4	10
Template 5	1

4.2 System usability

We also conducted verification and validation testing of the system's usability. As mentioned, an operator may have to change the operation sequence to match the actual situation. Therefore, we considered testing our mechanism for several typical situations.

- Multiple operations

Our mechanism can decide the operational priority for all operation templates. Even if several users operate multiple sequences, it can find all the templates that are being performed and display transit buttons corresponding to target pages.

We carried out multiple operations by computer simulation using the same data used for the simulation described in section 4.1 and verified that operators can avoid viewing irrelevant pages for each operation.

In this simulation, the pages available for display and the registered templates were small in number than those of an actual system. We plan to verify the system's usability by using a larger number of pages and templates. We will measure accuracy and operation times, which are useful measures of system usability. Additionally, when multiple users operate different sequences, the mechanism should display different buttons that match their objectives. We will investigate methods for doing this.

- Operation skips

Even if an actual operation is slightly different from the template, such as when the operator checks values on different pages, the mechanism should still be able to suggest the next step.

We carried out another computer simulation and verified that the system's suggestions were correct when we changed part of an operation sequence.

Since there are actually two types of operation skips, intentional and by mistake, we plan to investigate decision methods for both types.

- Operations with flexible sequence of steps

The ability to group operation steps, which enables operators to switch the step sequence, is an effective way to reduce the number of registered templates. For example, operation template 4 in Table 1 places steps 2–5 in one group. The total number of possible operation sequence patterns for template 4 is 120. As a result, there is great flexibility for actual applications.

For practical application, the mechanism should have transit buttons that have dynamic links and ones that have static links. This would enable an operator to use transit buttons for both normal plant operation and accident-condition operation.

5 Conclusion

We are working to improve the display interface of advanced monitoring and control consoles. The mechanism we investigated adds “transit buttons” with dynamic links for guiding the operator to the appropriate system-monitoring pages.

We plan to improve the forecast precision by using data from the alarm system and/or other support systems. We will also evaluate the usability of this mechanism by using a simulator that can run typical plant accident scenarios.

In addition, we will develop functions that reduce the operator's workload, such as one for automatically registering the operation templates.

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