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INTEGRATED KNOWLEDGE- AND SIMULATION-BASED FACILITY SUPERVISION AND CONTROL

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This paper presents the concept of integrated knowledge-based and simulation-based supervisory control for process facilities. Linked to a common SCADA system, such knowledge-based decision procedure, which includes process simulation, assists the operator and facility engineer in operating the facility. The functional chain, which begins with operator knowledge acquisition and moves to knowledge and facility modeling and finally to their integration into a real SCADA system, have been implemented and tested for a water treatment and supply plant.

1. INTRODUCTION

The increasing complexity of modern process plants and the demand for energy conservation, product quality, environmental protection, safety, and reliability call for new approaches to process automation. Along with decision-making and control procedures based on mathematical models and optimization solvers, knowledge-based systems involving the experience of human operators are a promising approach.

The aim of the integrated knowledge-based and simulation-based method is to combine available formal information and process data from the facility, e.g., information on plant models and historical operation profiles, with human operation knowledge. This calls for experience-based evaluation and active assessment of operation artifacts through an operator team and further use of this information in a regular manner.

This paper is devoted to advanced facility supervision and control concepts that simultaneously embrace simulation- and knowledge-based components. Focus is given to the decision-making processes of human operators and the respective modeling of knowledge objects for automatic processing. The aspects of system implementation and the example of their application presented are related to a real industrial environment.

2. ADVANCED FACILITY SUPERVISION AND CONTROL

2.1 Control Levels and Degree of Automation

The presented work focuses on the application of simulation- and knowledge-based systems in a process industry. Figure 1 shows the typical control and supervision levels in this field. SCADA systems (Supervisory Control and Data Acquisition) are usually introduced for high-level process control and automation. They play an important integrative function in distributed, multilevel control environments and provide the appropriate operator panels (HMI). Typical functionalities include the monitoring of process states, the recording of alarms and events, the activation of control actions, emergency shutdown, etc.

At control levels below SCADA, the favored system modularity, functional encapsulation, and real time requirements are considered and implemented. Furthermore, the aggregation of data on the way from process-level to high-level control is a main aspect of the multilevel approach (see Figure 1). Therefore, appropriate abstraction levels must be engineered to provide suitable views on plant conditions and process states for supervisory control and decision-making by human operators.

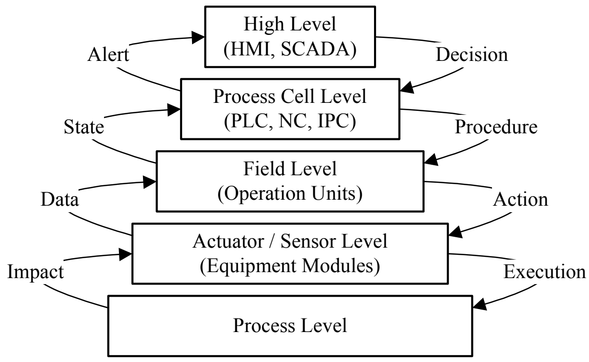

Figure 1 – Typical control and supervision levels in a process industry

2.2 Operator Integration

Even with a high level of automation of process supervision, diagnostics, and control, the facility operator's role is continually expanding. Although local automation tasks are covered by an installed control system, the facility operation staff must take precautions with high-level functional, technological, strategic objectives.

The human operator team is responsible for the high-level process management which includes tasks such as

- Assessment of process situations
- Selection of operating points
- Consideration of different modes of working and use of resources
- Reaction to changing requirements/demands
- Ensuring a continuous and smooth running of the system.

The decisions of operators are based on their knowledge of process situations, process trends, and process control. Here past gained experience, i.e., historical data and knowledge of situations, plays an important role in allowing a high level of performance to be reached (Lisounkin, 2004).

In our concept of an advanced supervisory and control system, the provision of support functionalities to the operator team plays an important role. It includes not only tools for decision support, e.g., through integrated simulation functions, but also methods and tools for arranging the automatic execution of favored process patterns. Here the need for optimization of system operation and the demand for a high level supervisory control should be met without compromising the benefits of the flexibility and knowledge of human operators.

2.3 Requirements on Simulation and Knowledge Processing

Specific technical realization, technological and administrative requirements, operative performance criteria, as well as long-term planning result in unique supervisory and control schemes for each facility to be controlled. Usually, the design, development, and maintenance of such supervisory and control schemes employ a significant amount of human resources for each application. Reasonable methods for modeling a corresponding knowledge base and techniques for its application and maintenance will lead to a high acceptance of such systems and efficiency in use.

Considering the acceptance by operators as a key aspect, an extensive use case analysis must be foreseen even at the very beginning of the development. Therefore, the system must enable different operation modes, such as manual mode, decision support mode, and automatic execution mode. Furthermore, automated functions must provide feedback on decisions in order to establish confidence and also to support the tuning of system behavior.

From the system integrator's point of view, two classes of requirements can be identified. On the one hand, there are clear technical requirements concerning functional integration concepts and interfaces with different SCADA systems. On the other hand, requirements concerning the acquisition and engineering of knowledge, the re-use of models and knowledge components, maintenance, and lifecycle support become of increasing importance.

3. OPERATION KNOWLEDGE MODELLING

3.1 Decision Making

The analysis and modeling of role-dependent staff responsibilities and activities in the context of process facilities and power stations have been studied by Rasmussen (Rasmussen, 1986). His findings continue to influence the development of decision support systems for technical facilities.

Within the facility operation context, the decision-making procedure consists of the following steps. First, the decision maker must detect the need for intervention by observing actual process data. For this, the operator has features at his disposition – data evaluation functions and criteria – which give him an estimate of the optimality and regularity of the system's operation or of a malfunction in the system. In regular cases, this information can give the direction for subsequent activities. Based on this evaluation, a target state into which the system should be put will be chosen, and the task that the decision maker should perform will be selected from a review of available resources. Once such a task is identified, the proper execution can be planned and carried out.

If the connection between the data evaluation criteria and the sequence of actions to reach the given goals is clear, the supervision procedure is considered "skill-based". In cases where decision-making involves the evaluation of alternatives, the supervision procedure is considered a "rule-based" behavior. A decision-making procedure which involves the comparison of models and analysis of goals and depends on the know-how of the operator is considered "knowledge-based". These three levels of the decision-making procedure are depicted in Figure 2.

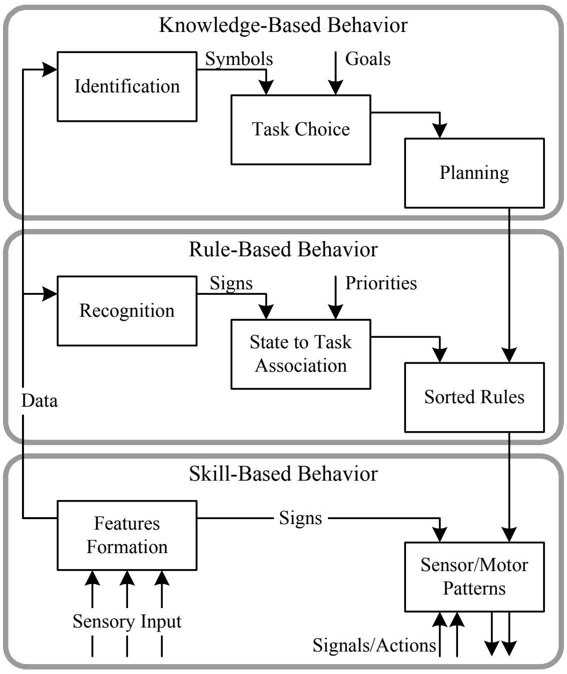

Figure 2 – Decision-making behavior model (according to Rasmussen)

3.1 Knowledge Levels

In integrated knowledge- and simulation-based supervision and control we consider the following three knowledge levels (see Figure 3):

- Knowledge based on process history and process states
- Knowledge based on process formal modeling
- Knowledge based on process operation experience.

Based on historical process data available from a SCADA database, typical process situations and patterns can be elaborated using data mining analysis and classification tools (Lisounkin, 2004).

Mathematical analysis and the modeling of process behavior result in numerical simulation tools which are applied extensively in assistance, support, and training tools (Schreck, 2002).

Acquisition and adequate use of operator experience is a rather difficult topic. It is the focus of much current research as well as the subject of our research activities. A rule-based approach to the maintenance and processing of operator knowledge is a promising method (Krüger, 2005).

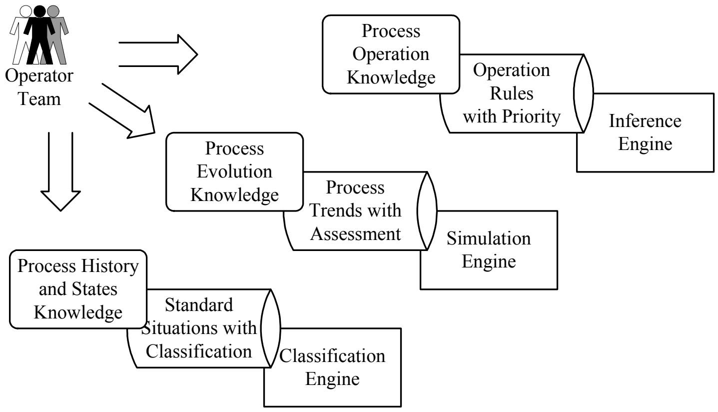

Figure 3 – Structuring of operation knowledge and related tools

3.2 Knowledge Objects

The knowledge objects include the following: resource, state, condition, rule, action, setpoint. “Resource” objects represent atomic processes or groups of processes on the corresponding hierarchical level. The entire facility is also an object of the type “resource”. Objects of this type are the source of information and the operation field for the decision-making procedure. For the decision-making procedure, the principle components of the resource objects are “state” objects, which collect measurable signals and indicators for the evaluation of facility states and provide an informational starting point for the decision-making process. For the evaluation of process states, objects of the type “condition” are specified. These objects represent data processing features - operators from a predefined set with “Boolean”-type result values. The arguments for these operators are the state variables of resource objects. The supervised system allows impacts which influence the future system evolution. The set of impacts correspond to the possibilities of the system operator to change the system behavior in order to achieve wished results. These impacts are modeled by objects of the type “action”. The action objects include objects of the type “setpoint”, where the reference to a corresponding resource object as well as the type of control impact and its parameters are encoded. The objects of the type “rule” link objects of the type “condition” with objects of the type “action”. If, in the case of some system states, a condition fails to be met, a corresponding object of the type "rule" provides an automatic reaction. The association of system states to control tasks is defined via the rule objects. In cases where alternative actions can be identified, the rule objects maintain priority over the action objects. A more detailed description of the knowledge objects by means of XML Schema is given in (Krüger, 2005).

4. SYSTEM IMPLEMENTATION

4.1 System Architecture

Several components must be added to the infrastructure of a process control system in order to provide the operator with new knowledge- and simulation-based supervision methods and facilities. This includes components for knowledge modeling, simulation, and visualization. The components can be grouped according to the phase in which they are needed: the development phase or the runtime phase. In this paper we focus on the runtime phase. Its architecture is shown in Figure 4.

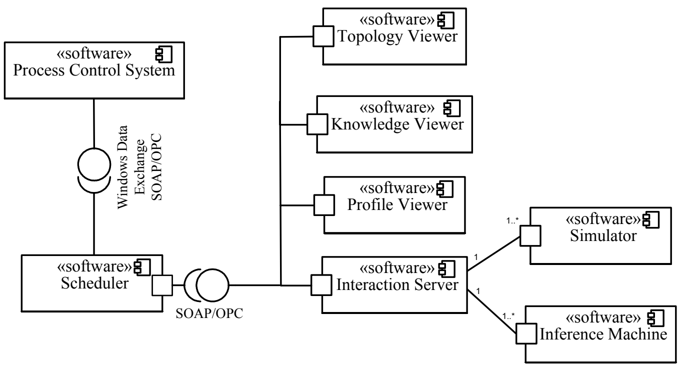

Figure 4 – Runtime components of the knowledge-based supervision system

The "scheduler" is the data and task control unit of the system connecting the existing process control system (SCADA) with the knowledge-based supervision. Typical tasks are the initiation, monitoring, timing and data exchange of components. In addition to process information performed by SCADA, the "topology viewer" provides processing and visualization of process states relevant for knowledge-based supervision, e.g., intermediate results of the calculations. It also reads in the simulation model and visualizes the dynamic behavior of the process. The "knowledge viewer" visualizes the selected and applied rules of the supervision system. This allows the operator to retrace the actions and the reasons they were executed. The "profile viewer" gives the operator an overview of the relevant operation history and actual context. The currently selected as well as all available operation trends are drawn as a diagram on the screen. The "simulator" forecasts the process values for the supervision components. Based on the current process values, the output values for a defined time frame are computed. This allows the "inference machine" to take preventive actions based on the knowledge provided. The current process states are checked constantly for rules violated. The "interaction server" allows the dynamic connection of multiple simulators and inference machines to the system architecture. Simulation and knowledge models can be split into subsystems but still appear as a single system to the scheduler through an encapsulation of the coordination of the subsystems.

The presented architecture has been prototypically implemented and tested within an industrial environment. More detail concerning interface generation and task scheduling is given in (Schmidt, 2005).

4.2 Application Example

A system application and test of the implemented components was performed at a water supply and distribution facility equipped with an advanced SCADA system. The main objective of the facility supervision and control was to ensure a proper operation of the system. For this, the following criteria had to be fulfilled:

- Allocation of the required quantity of pure water
- Consideration of the different modes of working and use of resources
- Compliance with requirements for the quality of water
- Adherence to a minimal consumption of energy
- Maintenance of the purification cycle of individual water filters
- A continuous and smooth running of the system
- Adherence to the prescribed limits of the tanks with a quick reaction to deviations.

Figure 5 shows the user interface for simulation-based operator support and the main topology of the process plant. Real plant operation profiles (historical data) spanning two years as well as knowledge of system operation have been gathered for the implementation of the knowledge-based supervision and control system.

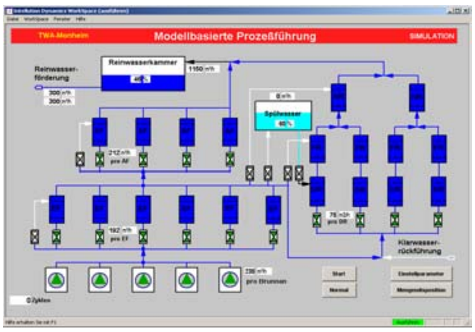

Figure 5 – Example of water facility plant operator interface (SCADA GUI)

Here available simulation models of the facility have been extended, and the required knowledge objects have been implemented. A SCADA module for automatic plant control was used as a reference for specification and testing of operation rules. The challenge was to show the applicability and flexibility of the proposed approach with respect to the integration and adaptation of the operation knowledge available to facility engineering and operation staff.

The set of operation rules includes about 60 items. By means of these rules, the number of possible facility states was reduced from about 10,000 to about 100. During the operation, the inference machine had to take its decision within this pool of 100 allowed states.

The interaction of inference machine and simulator and the functional behaviour were tested, and the tuning to the expected operation profile was able to be shown. Furthermore, the overall functionality with respect to the interaction of all functional components and the interface to the process control system was successfully tested.

5. CONCLUSIONS AND OUTLOOK

The developed concept of integrated knowledge- and simulation-based facility supervision and control was prototypically implemented and tested within a SCADA environment for water supply stations. The expected functionality and interaction of the runtime components in response to the process control system were approved. Further research activity will be devoted to the respective modeling and engineering tools. Additionally, the relevance of this concept to other applications will be investigated: in particular, in regard to gas distribution networks and storage facilities.

6. ACKNOWLEDGMENTS

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