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Design of Intelligent Information Support Systems for Human-Operators of Complex Plants

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Abstract. Complex equipment of an industrial plant subject to control, large body of information flows, complexity of control problems, lack of time available to make a decision, etc. are the reasons which lead to a number of cases to contradiction of human-operator control capabilities and actual control problem requirements. Within such a problem, a natural way out is to design an intelligent information support system (IISS) which would be able to assist the human-operator to implement the complex industrial plant control functions. These functions are to involve operative mode control of automatic systems, monitoring the systems performance, and prediction of the plant status, both within normal and abnormal situations. Involving such an IISS into control process enables one to decrease the human-operator load, to increase the human-operator performance, and to increase the plant performance reliability.

1. TASKS AND STRUCTURE OF IISS

To design an IISS, one is to integrate as whole conventional algorithmic techniques of control of complex industrial plants and an intelligent technology paradigm. Within the scopes, the algorithmic techniques are used in cases when corresponding knowledge is of the concise, sharp-cut, well-defined, formalized form, while the artificial intelligence techniques are applied to a number of mildly formalized problems arising under control of complex dynamic systems. These problems are characterized by imperfection, ambiguity, ignorance of initial information, and by use of corresponding rules of the information processing.

In accordance to the above reasoning, the IISS tasks may be related to (Byvaikov et al., 2002, Byvaikov et al., 2006, Poletykin et al., 2002):

- assessment of the current status (situation);
- prediction of the plant behavior under normal operating mode;
- prediction of abnormal events expansion;
- elaborating and assessing possible human-operator control actions as well as selecting the best control actions, etc.

A feature of the IISS is its ability of behavior planning, adaptation, and learning. To implement the feature, the IISS is endued by a powerful hierarchical control structure. Within such a structure, at least the following three levels are of the most importance: the level of strategies, the level of tasks, and the level of components (modules, subsystems). The highest level, the level of strategies, determines ordering, implementing or stopping tasks solving. Also, the level organizes an interaction between the tasks. Provided that some tasks are selected at the level of strategies to be implemented, at the level of tasks it is determined which components are to function to solve the selected tasks. Finally, at the lower level, the level of components, the component function is controlled, with the components solving partial subtasks.

In the IISS, the role of the hierarchical control arrangement is implemented by an intelligent monitor which is presented in fig. 1. The monitor

- controls the system performance;
- determines when and which tasks are to be implemented;
- implements functions of intelligent configuration to realize automatic design of a functional scheme of information processing at the level of components in accordance to the tasks arising during the plant performance;
- realizes interaction between the system components, human-operators, and data sources;
- controls data flows;
- coordinates local solutions obtained by local subsystems;
- simplifies the human-operator interaction with the system by coordinating assessment and rationale of the proposed solutions, finding out another solution variants, clarification and revising of solutions adopted earlier, assessment of solutions proposed by the human-operators, obtaining reference information on events arising at the plant.

Another important part of the intelligent monitor is a kernel which implements the lower level control of the system in its

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entirety. Design of such a kernel is to insure its effective and predictable performance.

Basic functions of the kernel are realization of interaction between the system components by use of a message transfer mechanism, and dispatching jobs in the system in order to ensure real-time performance.

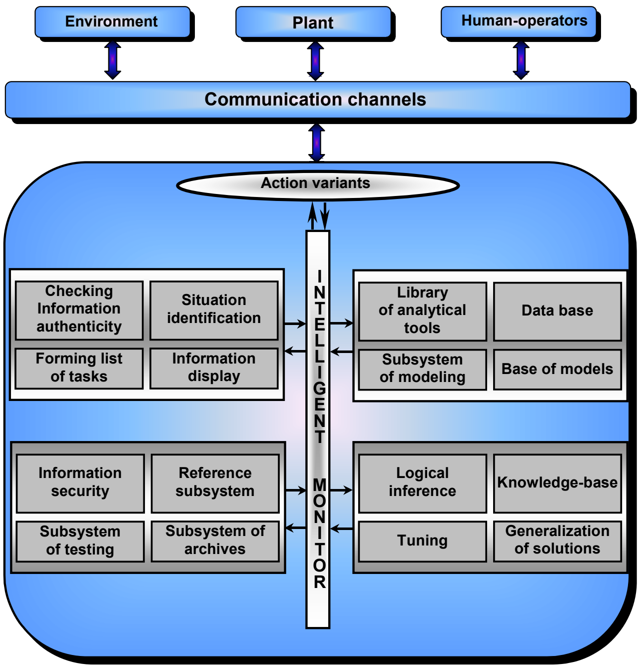

Fig. 1. An Intelligent Information Support System for human-operators

2. IISS DESIGN STAGES

An IISS design process involves the following basic stages (Byvaikov et al., 2006, Jharko, 2004, Zharko, 2006):

1) Design of the intelligent monitor.

2) Design of an informational interaction of the IISS with the environment in order to obtain necessary information for decision making. The IISS is to understand the input information. This is achieved by IISS intelligent tools of recognition of the entering information, checking the information authenticity, situation identification, forming a list of tasks requiring the decision making.

3) Design of the IISS as a distributed system what increases its survivability and the operation speed. Within the scheme, the idea of organization of the distributed IISS is that the local IISSs inform each other on their purposes and actions within the common decision making.

4) Design of a knowledge base (KB) and inference device reflecting in time the logic of events taking place both at the plant and in the environment.

5) Design of a tuning subsystem which is to provide an interaction of the human-operator and IISS. A basic function of the tuning subsystem is to bring out the human-operator preferences during preparing the IISS to the operation and formalization of the preference sets to be used in the IISS.

6) Design of an informational search system based on the hypertext technology. Since a human-operator, during his work, is to process large bodies of semantic (notional) information, the he / she needs corresponding information support. The hypertext of the IISS is to come near, in its functional abilities, to modern expert systems. Besides the KB, such a hypertext system is to have a reach human-operator interface as well as tools providing changing and updating the KB. Within the technology, the role of the “decision maker” is to be played just by the human-operator using the hypertext.

7) Design of a modeling subsystem. To model the plant performance and environment, it is helpful to implement most of the intelligent functions in automatic (or semiautomatic) mode. This can be achieved by use of the artificial intelligence within simulation process. In turn, the modeling subsystem is to use various mechanisms of entering, interpretation of data in the KB in order to obtain the required information on the plant subject to control.

8) Design of an intelligent user interface. Taken separately, the interface abilities of different subsystems and tools of the IISS may be quite simple. However, when integrated into an IISS, they form a new quality of complexity. The following abilities of the user interface of the IISS are advisable to be chosen as basic ones:

- the IISS is to assist the human-operator under interaction by use of intelligent agents which are knowledge-based systems providing interaction with others agents, network sources, and the user (Freeman, 1990, Ford et al., 1993, Gorodetsky, 1996, Serrano, 1991);
- the information process of interaction of the human-operator with the IISS is to be organized in accordance to various types of tasks to be solved: plant status monitoring, environment monitoring, decision making support, faults representation and displaying;
- the human-operator is to see the information generated by the IISS, superimposed on real-word images;
- basing on the KB, the IISS interface is to support speech understanding and structured natural language;
- the principle of information stratification is to be realized to provide the plant investigation by different specialists from various points of view.

3. METHODOLOGY OF IISS DESIGN

To design high performance intelligent systems of processing and utilizing knowledge under uncertain conditions, one needs to combine artificial intelligence techniques and advanced technologies of software design.

A feature of the IISS, as an intelligent system, is involving knowledge bases used within various functional units of the system. A number of knowledge representation tools may be used to represent different types of problem domains by the most effective manner (Popov et al., 1996). Under a KB design, one should analyze the problem domain to achieve the best combination of the object-oriented approach and other models of knowledge representation within the functional units. For example, using the fuzzy logic combined with the object-oriented technology may hardly decrease the number of rules required. So, the fuzzy logic based KB design has been demonstrated as an effective tool to be used within modeling complex plants under uncertainty.

The IISS design faces with the following complex problems listed below.

- At present, there exist no complete intelligent control theory, and many scientific and engineering problems are still to be solved.
- A knowledge base filling process is excessively complicated and time consuming.
- At present, the level of development of intelligent tools to organize the human/system interface is not high enough.
- The IISS design is a time consuming and expensive process involving a coordinated work of large groups of developers.

The problems listed determine the following principles of IISS design: ability to extension, independent design of different components, distributed structure.

To follow the principles, the system is proposed to be based on the concept of extensible programming. Such a principle is considered as a possibility of design hierarchies of modules, which provide each module to add a new functionality into the system. Extensible programming assumes that adding a module does not require involving any changes into the already existing modules. The new modules add new procedures and add new (extended) types of data, with the latter being even more important than the former (Pescio, 1998).

To realize the concept, a structure of the IISS is proposed which is based on combination of the client/server model and object-oriented model. The idea of the client/server model is separation of the IISS onto several servers, with each of them realizing a given set of functions. A possible separation of the system is presented in fig. 1.

A client may be represented both by another system component and a program executing a control action of the human-operator. The client asks for function implementation by sending a corresponding message to the server. The intelligent monitor delivers the message to the server. After implementation of the function required, the intelligent monitor returns to the client the results using another message.

Use of the client/server approach leads to a system consisting of autonomous components of relatively small bodies. Different servers may be implemented at different computers. This is well-coordinated with the concept of distributed calculations.

Microsoft Corp. has elaborated a technology of component design referred as COM (Component Object Model) (Rogerson, 1997). Components designed on the basis of the COM meet the following two important requirements. These are: COM components consist of executed code and are dynamically linked up to each other; COM components are connected to each other by interfaces and encapsulate details of realization.

Due to the above features, a system designed on the basis of the components realized in accordance with the COM standard possesses a number of essential advantages, such as listed below.

- Updating or extending the system reduces to substituting a component by that of a new version. Dynamic assembling enables one to change the component itself without reassembling the total system.
- A client is connected to the component by the COM interface. If the component is updated but preserves its interfaces, then the system performance will not be broken down.
- Dynamic assembling assumes the components to be translated and linked, i.e. to consist of executed code. Thus, COM components hide the programming language used. This enables the components to be designed independently by different groups of developers using different programming languages.
- COM components are transparently moved over the network. Client works equally both with remote and local components.

Another part of the proposed concept of the extensible programming is the object-oriented model. The object-oriented approach enables one to design a natural and flexible model of a complex hierarchical system. Within the approach, the hierarchical nature of such a complex system is reflected as a hierarchy of classes.

In the system, the objects are representations of the real-word elements, which are used to solve tasks which have been posed for the system. Each of the objects is associated with a set of parameters reflecting essential properties of the object.

Under object-oriented approach, introducing changes into the project at each stage of the system life cycle does not require total revising the project. These are of a local nature. Such a change or addition influences only on required classes and objects. Detailed specification of the project is involving new classes which may inherit the behavior of the classes designed earlier. The object-oriented approach enables one to design of a prototype of the system fast, with sequential extension of the prototype being implemented in order to obtain the finally desired result.

The basic stages of the object-oriented system model design are:

- object domain analysis and determining classes, their features and methods;
- design of the hierarchical class structure based on the mechanism of inheriting;
- analysis of connections and interactions of the objects.

4. TOOLKITS FOR IISS DESIGN

Toolkits for the IISS design are to support the life-cycle of the application by use of:

- object-oriented approach, graphics environment, and structured natural language, which provide fast design of the application prototype;
- object libraries and functional modules which assist to decrease the time required for the application design;
- repeated use of objects and modules within further applications;
- inference mechanism possessing tools decreasing exhaustion, abrupt event reaction-time, and possessing a reach set of tools of rule generation;
- multiple access to central knowledge base and group application work;
- simultaneous connection with several data bases and others program systems;
- real-time interaction with external environment;
- an interactive editor enabling designers to create rules, procedures, and models using structured natural language, as well as enabling automatic eliciting errors;
- support mechanisms of testing and verification of the application, involving dynamic simulation to validate the application performance under various scenarios;
- simultaneous design of the application by several groups of developers;
- transition to new computational platforms without reprogramming.

In particular, intelligent toolkit real-time system G2 elaborated by Gensym Corp. (USA) (Popov, 1996, Gensym, 1992) (fig. 2) possesses the above properties.

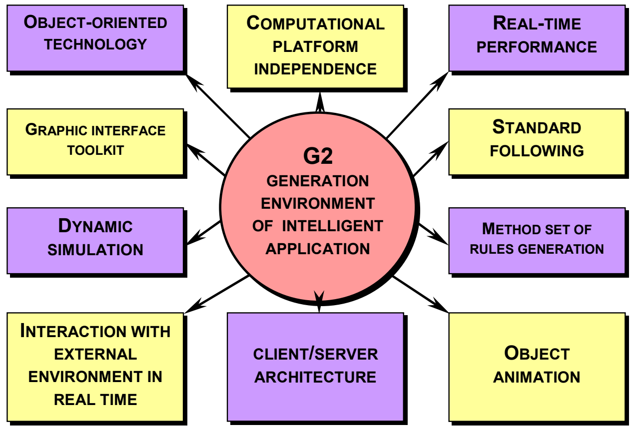

Fig. 2. Intelligent real-time toolkit G2

The toolkit is elaborated to support an effective design of complex intelligent systems and provides creation of applications, design of which would be too hard and expensive when based on conventional software, say programming languages C or C++ (Poletykin et al., 2006, Promyslov et al., 2005).

Due to G2, the designed intelligent system is supported by platforms Windows, Unix, VMS; is supported in Internet; supports data bases ORACLE, Sybase, Informix, DBC; supports clients written in Microsoft Visual C++ and Visual Basic; support advanced network technologies.

A flexible simulation complex (FSC) possesses the same properties. The complex is used to design the IISS for human-operators of a nuclear power plant (NPP) (Bajbulatov et al., 2001, Jharko, 1999a, 1999b, 1999c, 2004, Jharko et al., 1999, Jharko and Motulevich, 1997, Zharko, 2006). Fig. 3 presents the functional scheme of the FSC. In the FSC, all modules of the FSC may be used both jointly and independently, all modules are based on a set of main operations which involve:

- data acquisition;
- checking data authenticity;
- optimization;
- modernization of adaptive models;
- graphic user interface.

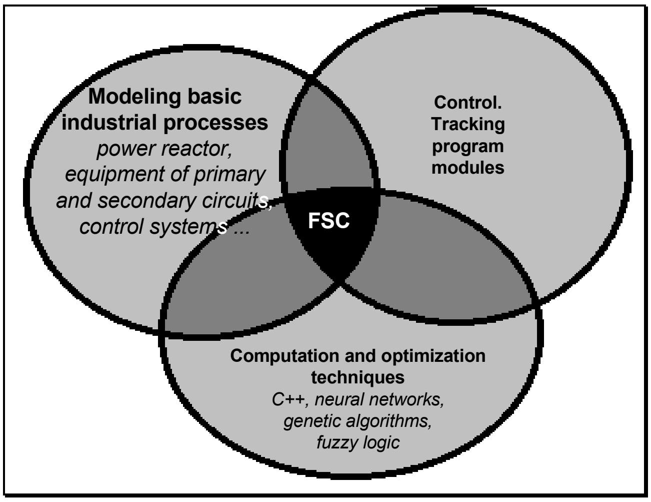

Fig. 3. Functional scheme of the FSC

Conventionally, a design process, concerned with both large scale models and industrial plants, requires large expenditures of design time and a number of other resources. In contrast, a computer modeling which uses a flexible simulating complex (FSC) is an effective alternative way, in costs and various engineering decision making criteria, of solving the problem. The entity of such a flexible modeling is multiple using various program code modules as unified and standard components of different complexes of program codes. Within the flexible modeling approach, a universal model of a nuclear power plant (NPP) unit has been elaborated. Since there exist no absolutely equal NPP units, there exists a need to elaborate a FSC which could be tuned in operative mode to any existing or designed NPP unit, and which could also be tuned to any change in the NPP unit equipment, or in the NPP unit control system. Thus elaborated, the FSC involves models having different complexity and detailed elaboration, what enables one to implement prediction computations for NPP unit industrial processes without essential loss of accuracy. A structure scheme of the FSC performance corresponding to a NPP unit parameter modeling is presented in fig. 4.

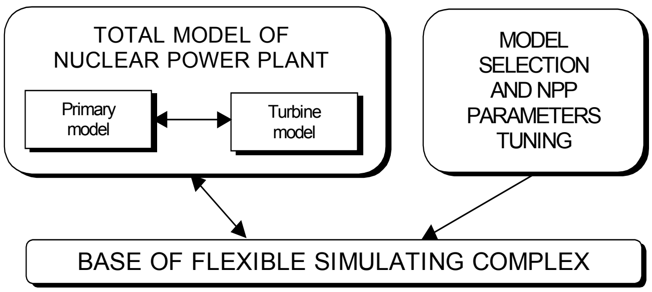

Fig. 4. A structure scheme of the FSC performance corresponding to a NPP unit parameter modeling

The FSC elaborated is built by use of the module principle. Within it, all industrial equipment is partitioned onto groups, with each group being described by a separate functional module (block). Most of these functional modules have several variants of computer implementation. These variants differ one to another in details and completeness of description of corresponding parts of the equipment and technological processes, and, consequently, computational characteristics (CPU time, on-line storage, etc.).

Design and modeling tools composed within the FMC (Jharko, 2004, Zharko, 2006) have the functional structure presented in fig. 5.

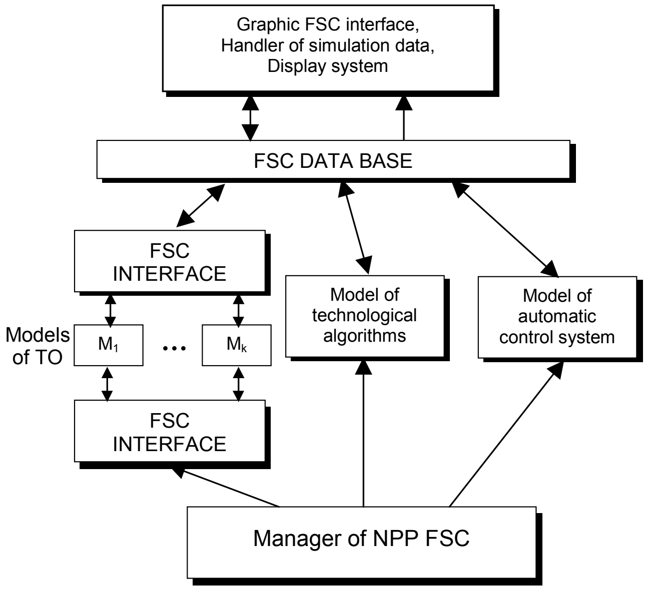

Fig. 5. Scheme of functional module of the NPP FSC

5. CONCLUSIONS

The paper has presented an approach to design an intelligent information support system (IISS) to be used as a human-operator assistant under control of large complex industrial plants. The human-operator functions are to involve operative mode control of automatic systems, monitoring the systems performance, and prediction of the plant status, both within normal and abnormal situations. In turn, involving the IISS into the control process enables one to decrease the human-operator load, to increase the human-operator performance, and to increase the plant performance reliability. Tasks and structure of the IISS, the IISS design stages, methodology of IISS design, toolkits for IISS design have been considered. A flexible simulation complex (FSC) as such an intelligent toolkit has been presented. The complex is used as a “kernel” of the IISS for human-operators of a nuclear power plant.

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