

Web-based Process Control Systems: Architectural Patterns, Data Models, and Services

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Abstract. In our paper we discuss results of the real-life project in the domain of Information Handling Systems for Technological Process Control (TPC-IHS) development in the gas-transport and gas-production branches in the Ukraine. We emphasize important requirements, which have to be satisfied by analyzing and designing of Web-based TPC-IHS. *Architectural design patterns*, which were elaborated with respect to real-time operating mode issues, and multi-level distributed topology of TPC-IHS are presented using UML-notation. We introduce the *Integrated Node Database* model, which includes the process-oriented storage structures and appropriate functionality. *Advanced Services Collection* for TCP-IHS functionality, which supports the main activities needed to be provided for process coordination and control, is also proposed. Using these pattern solutions and data modeling concepts, appropriate reusable software components can be developed, and some of them already have been implemented successfully in our projects, and we finally introduce some screenshots of our Web-based applications.

1. Information Handling Systems for Technological Process Control – “state of the art”, common features, enabling technologies, and modern trends

The technical problem of complex technological processes automated control in the real-time mode remains actual and important nowadays. As the main reasons of such actuality the large time and cost constraints of such systems, as far as the strong requirements to their reliability and stability can be distinguished. Such computerized systems should support such actions as receiving the data from technical controllers and devices, performing the control commands and actions, representing the actual

state of controlled technological processes, supporting the decision making process of operating staff, etc.

The main distinguishing features of information handling systems for technological process control (TPC-IHC) can be considered as the following:

- The architecture of such systems is mostly distributed
- The working cycle is continuous (so called “24x7” mode)
- The system topology is characterized with the large-scale and multi-dimensional relationships between several subsystems
- The used data resources are heterogeneous
- Such systems are supposed to include legacy software applications, as far as additional modules and subsystems
- Systems should support the various types of user actors and their groups
- The problem of user’s support in some extreme operating cases (the analysis of failures, devices trouble-shooting, ad hoc queries and commands, etc)

One of the main international trends in the domain of TPC-IHS development is the usage of SCADA (Supervisory Control Access and Data Acquisition) system concept[1-4]. This class of information handling systems could be considered as an extension of CAD/CAM systems family, determined by hard-ware devices level, which they are interfacing with. Typical SCADA system is a special software solution facilitating a lot of programmable logical controllers (PLCs). The main goal of SCADA system is to collect the technological process data, to represent them in proper time and form, and to accomplish the necessary control actions.

According to our investigations and experience, we suppose, that using of Web-technologies can successfully solve a problem of complex TPC IHS design. Most of all, we are guided by the following reasons and considerations:

- The usage of TCP/IP and HTTP protocols allows to solve the problems of distributed applications design and development, and their stable functioning, even in the situation, when communication links and channels have a low capacity and work seesaw
- Internet environment shows the best correlation with the paradigm of TPC IHS functioning in the “24x7” mode
- Such Web-standards and technologies, as XML, DOM, RDF, and their browser-tier support can provide the heterogeneous data integrated processing in such systems
- The server-side and component programming technologies, like ActiveX and ASP (Microsoft Corp.), or EJB and JSP (OMG and Sun Microsystems) can be an effective platform for legacy software integration.

2. TPC-IHS in the Ukrainian Gas-Field Industry – our project description

During last 3 years our R&D group has fulfilled a number of projects aimed to the TPC-IHS elaboration for gas-branch enterprises. Some results of these projects were presented in [5-8]. Let’s consider now our applied-oriented approach to design the architecture of Web-based regional information handling system of dispatch control

for the gas-productive manufactures in Kharkiv region (Ukraine). Such system will allow:

- To provide the continuous and quick access to the required information related to the all technological processes and objects in the regional system. Such access will be possible in the authorized mode from every node of such system, as far as from vehicular communication devices (laptops, mobiles)
- To provide the hot link between system users (e.g. operator in gas-extraction node can obtain the technical advise information from an expert in regional management center)
- To store, systemize and analyze the all the information, which could be necessary for the preparation and making the day-to-day and strategic decisions, concerning to the technological process control and dispatch reporting

During such IHS design and implementation the fundamental principles of modern complex information systems development, such as Open System Architecture – OSI standard, object-oriented analysis and design of the whole system and its separate components structure – OMG and ODMG standards[9], heterogeneous information resource integration, and others, as far as appropriate information technologies for Web-based information systems design and development, including UML as a notation for system structure modeling and complex software design, MS COM+/MS .Net and ASP as component technologies for Web-programming (or their alternatives, such as J2EE and JSP), modern database management systems, such as MS SQL Server 2000 and Oracle 9i, the standards for structuring and processing of large volumes of heterogeneous data resources in Internet/Intranet (XML, RDF, DOM). Usage of these principles and technologies should provide the high scientific and technical level of the project and its implementation, as far as the possibility of continuous and effective system reengineering realization in future.

The proposed regional dispatch system has the distributed multilevel network architecture, each level of which will include the Web-oriented software package (WSP), meant for storing, representing and analyzing of technological information. The following levels of the proposed architecture can be distinguished:

- *Gas Field level* – the WSPs of the gas-fields concern to this level.
- *Sectional level* - this level represents the organizational union of several neighboring WSPs.
- *Regional level*. The node of this level includes the WSP for top-level branch management, and the main goal of it is to support the decision making process for the whole distributed technological system control.

The system architecture described here is open – it means that it is possible to add the new logical levels, from one hand, to cooperate with national and international branch management organizations, and, from other hand, to include some additional intermediate nodes for technological data processing.

3. Architectural Design Patterns

Designing such complex IHS, we propose to use the approach, based on the design and elaboration of *architectural pattern solutions*, and on their basis, reusable software components. It allows to provide the standard way of design and

implementation of whole distributed TPC-IHS. We can emphasize the following pattern solutions and their corresponding software components:

1. *Integrated Node Database (INDB)* – it is used for storing and processing all the information, which is necessary to the WSP functioning.
2. *Data Exchange Server (DES)* – the component, which supports the data exchange with the controllers of technical devices, which are the components of appropriate system node.
3. *Data Visualization Service (DVS)* – the set of server- and client-side components, which provide the visualization of technological process.
4. *Data Synchronization Service (DSS)*– also is represented by the set of server- and client-side components, which are aimed to synchronize the data in the different system nodes.
5. *User Accounts Manager (UAM)*– this component is necessary for providing the data access rights for the system users.
6. *Advanced Services Collection (ASC)*– represents simulation models and appropriate software tools and packages for the decision support making.

These system architecture components are presented in the form of UML Component Diagram on Fig.2.

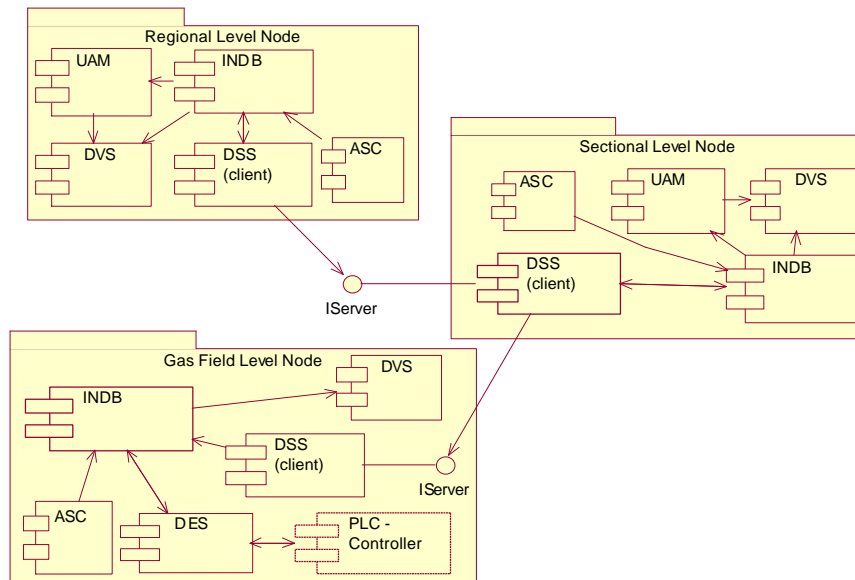


Fig. 1. The aggregated system component diagram

The components on the diagram are grouped in the packages, which aggregate the functionality of the following possible types of system nodes:

- **Base level node:** the main feature of such level' node package is the special component – controller of external devices (marked on the diagram)– which serves as the data source for whole the system. Also the parts of this package are: Data Exchange Server (DES), Integrated Node Database (INDB), Data Visualizing Service (DVS), and Data Synchronization Service (DSS). The

last component provides its interface (IServer) to the client, the role of which is played by the data synchronization application of higher level node, so we can consider the whole package as a server with respect to the higher level node.

- Group level node: the package of this levels' node includes such additional component as User Account Manager (UAM), which provides the user's domain functioning in the given level. The DSS of this level' node (with using of its IServer interface) serves as data server for the next level node.
- Regional level node– this is the root node in the hierarchical system. and its structure is the same as the structure of group level' node, with the only difference in the Advanced Services Collection (ACM) component, which can be used on this level.

4. Node database concept and domain-dependent data presentation

Integrated Node Database represents a component, which is meant for storing and operating the information needed for the ensuring of all the node software functioning. Designing such database structure, we had considered the modern trends in relational and post-relational databases (e.g.,[10]), with special respect to temporal data models (e.g.,[11]). The structure of Integrated Node Database (INDB) component can be represented as a set of several sub-schemes: $INDB = \{RDB, TDB, ADB, SDB\}$:

- RDB – *Retrospective Database*, stores and operates the retrospective information, which characterizes the technological process functioning.
- TDB – *Technological Database*; it is used for storing the configuration information needed for Data Exchange Server.
- ADB - *Account Database*, it is needed for storing and manipulating the information about users profiles and rights.
- SDB – *Synchronization Database*. This sub-scheme stores the information necessity for Data Synchronization Service.

The implementations of proposed INDB structure can exclude some of the sub-schemes, e.g. on the node, which serves only as a data bridge or storage and doesn't collect its own technological data, the TDB component can be missed, also it can be a situation, when INDB doesn't include ADB.

The domain concept assures the retrospective data delimitation in the distributed multi-level information system. The user's possibilities of information access in such system are determined by two factors:

- User's rights to access the information
- The location of a node, in which the current user has its account, in the whole structure of multilevel system.

As long as INDB component should not only store the necessary technological data, but also provide the means for their using in making the decisions of day-to-day and strategic control, the special tool - *Supervisory Rules Engine* – is proposed to be a part of INDB. The rule concept was originated in order to extend the functionality of RDB and to support the automatic processing of technological data in non-regular situations, which can happen during the technological process progress. Rule (R) can be defined as a set of *Conditions* (C), which determine the rule response; *Action* (A),

which should be provided in the case of conditions fulfillment; and *Rule Internal Parameters* (RIP), which set the features of its functioning. Thus, the structure of *Rule* can be represented as: $R=\{C,A,RIP\}$. In our application domain three components of the rule are specified as the following:

- Condition represents an event or a logical expression, which operates with the current values of technological parameters
- Action is defined as the set of parameters, which values should be stored in the separated storage
- Rule internal parameters define the time periods of rule activity (before and after the rule start), its maximal duration, frequency of data input, and others.

5. Advanced Services Collection

Advanced Services Collection (ASC) component is meant for providing the support in decisions making to the management staff of such complex technological systems. Commonly, at the top level of the system the decisions are made taking into consideration the interests of the whole distributed system, which are defined by a number of indexes (such as profit, social problems, ecology, safety of the system, etc.). Within a scheduled period $[1, T]$ we will present them as a trajectory $\{P_i^t, i \in I, t \in [1, T]\}$ where P_i^t is a vector, components of which define parameters of the i -th index during the t -th time interval of the considered scheduled period. Let's assume that the vector function (1) defines the degree of deviation from the given indexes where \hat{u}_j^t is a specific value of the vector u_j^t , that defines the output nomenclature and quantity of the j -th enterprise during the t -th year (subperiod). For solving the problem of vector function

$$\Phi = \left\{ \Phi_i \left(\left\{ P_i^t, \left\{ \hat{u}_j^t, j \in J \right\}, t \in [1, T] \right\} \right), i \in I \right\} \quad (1)$$

optimization the control actions are used that are defined by the vector

$$\mathbf{g} = \left\{ \mathbf{g}_j^t \right\} = \left\{ \left(\bar{\mathbf{g}}_j^t, V_j^t \right), j \in J, t \in [1, T] \right\} \quad (2)$$

where J is a set of the coordinated enterprises at the second level of hierarchy. The component $\bar{\mathbf{g}}_j^t$ is a vector defining control actions for the j -th enterprise in the t -th year. The vector V_j^t defines the parameters of the recommended functioning area $D_{oj}^{dt}(V_j^t)$ of the j -th enterprise in the t -th year in the space of its functionality U defining the output nomenclature and quantity. Assume that $\mathbf{g} \in \Gamma$ where Γ is a range of changing the control actions.

The approach noted above is discussed with more special details in [12], where the problem of technological processes coordination at the level of a separate enterprise is solved. Here we would like to notice only, that such formal methods can be attracted and used in the process of complex distributed technological system control, so the appropriate software components realized them are included in ASC.

6. Some TPC IHS implementation issues

By now, our R&D group accomplished the implementation of all the principal components for base level node WSP, and it was successfully implemented on Ulyanovka gas field (Kharkiv region, East of Ukraine). On Fig. 2 we present user interface example, which allows the system operator of this gas-field to check all the main technological parameters, receive and process the system messages and so on. The data exchange between system components is realized with the means of HTTP protocol by the transporting of XML-documents, which include the parameter values. The fragment of such XML document is shown on Fig.3.

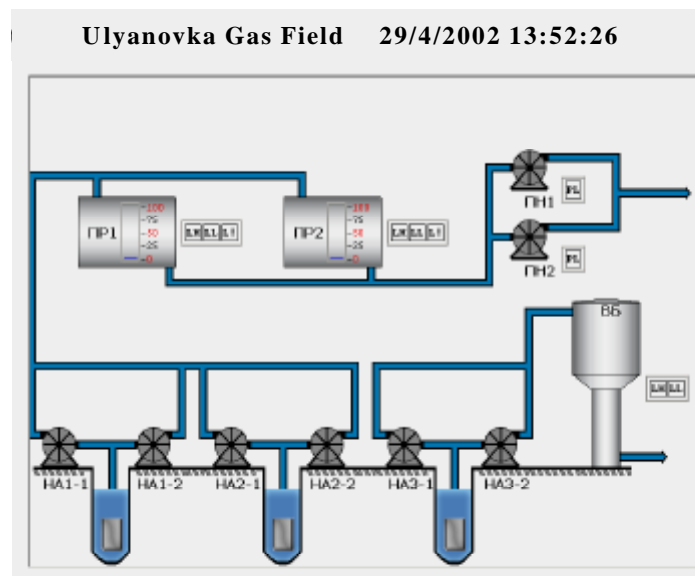


Fig. 2. The example of operator interface

```
<?xml version="1.0" encoding="WINDOWS-1251"?>
<facility name="Ulyanovka Gas Field">
  <message id="1">
    <number>121</number>
    <title>The tap #13 is open</title>
    <type>Ordinal message</type>
  </message>
  ...
  <parameter id="1">
    <name>Gas pressure in separator</name>
    <value>15,2</value>
    <dimension >MPa</dimension >
  </parameter>
  ...
</facility>
```

Fig. 3. The fragment of XML document with technological parameters values

Conclusions

In the paper we discussed the results we have achieved in TPC-IHS development for the gas-productive enterprises in Kharkiv region (Ukraine). The main features of TPC-HIS were discussed, and the possibility of Web-platform using for the development of systems with such features and requirements was proved. Also we presented the set of architectural patterns solution, which can provide the functionality of all the system levels and nodes. Implementation issues for some of the described patterns solution were also presented.

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