Bakhyt K. MUKHANOV[1], Waldemar WÓJCIK[2], Zhanar Zh. OMIRBEKOVA[3], Yerbol Zh. ORAKBAYEV[1]

K.I.Satpayev Kazakh National Technical University (1), Lublin University of Technology (2),
Almaty University of Power Engineering & Telecommunications (3)

doi:10.15199/48.2017.05.27

Application of Virtual Training Model for Technological Processes

Abstract. *Constant and efficient operation of technological processes without incidents is of a paramount importance for any enterprise. Nevertheless, if any incident happens, the operation staff should be properly trained in order to avoid serious consequences and such training should be as close to the reality as possible. Virtual training application (VTA) that we introduce by this paper can perfectly meet this target and can be widely used for effective staff training by modern companies and enterprises. This paper proposes VTA plans and specifications considering technical requirements and rules applied for production processes and training simulators. It elaborately presents how the simulation technology can be used based on the example of uranium in-situ leaching process analysis. Introduced VTA plans and specifications can help the training operator staff learn and simulate the mentioned above process and this knowledge can be obtained without interruption of the working process of an enterprise. Virtual simulator is based on a simulation model of the technological equipment, and the difficulty level of training and further development of the dynamics of the training developed with the help of artificial intelligence.*

Streszczenie*. Ciągły i efektywny przebieg procesów technologicznych, bez występowania sytuacji nietypowych ma kluczowe znaczenie w działaniu każdego przedsiębiorstwa. Niemniej jednak, w takich przypadkach obsługa powinna być właściwie przeszkolona, co powinno zostać przeprowadzone w warunkach możliwie jak najbardziej zbliżonych do rzeczywistych. Niniejszy artykuł prezentuję aplikację wirtualnego trenażera (VTA – virtual training application), który może zostać szeroko wykorzystany w praktycznym szkoleniu personelu. W artykule zaprezentowano ponadto obejmowane przez VTA scenariusze działania, które biorą pod uwagę reguły i wymagania techniczne związane z danym procesem wytwórczym. Działanie VTA zostało pokazane na przykładzie technologii procesu ługowania uranu in situ. Zaimplementowane plany i specyfikacje pozwalają szkolonemu personelowi zrozumieć specyfikę wspomnianego procesu, co odbywa się bez jakiejkolwiek ingerencji w działanie przedsiębiorstwa. W trenażerze wykorzystano modele symulacyjne rzeczywistych urządzeń, a funkcjonowanie całości, dla różnych poziomów trudności trenażera, zostało zamodelowane dzięki zastosowaniu metod sztucznej inteligencji. (****Aplikacja wirtualnego trenażera procesów technologicznych****).*

Keywords: training application, technological process simulation, control system, SCADA.
Słowa kluczowe: Aplikacja treningowa, symulacja procesu technologicznego, system sterowania, systemy SCADA.

1. Introduction

Electronic examiners trainer (1), static (or logical dynamic) trainer (2), and dynamic trainer (3) are three main types of computer trainers that are diverse by structure and function.

The most elementary type of the software is an electronic examiners trainer (1) that is a list of questions with images like schemes and videos and with answers in the form of simple test or those specified by trainee. The main purpose of this trainer is to act as a life examiner and to check the accuracy of entered replies to the set questions.

The second type of trainer that is a static trainer (2) is more complex comparing to the first one. It provides its users correctness and action methods control. This training method is based on the ascertain sequence of actions without application of mathematical models. Even if the sequence of actions may be sprayed into subtypes due to logical conditions it is still strict and unchanged and this causes difficulties in using of such software.

The third and the most effective type of trainer is a dynamic trainer (3) that offers trainees enhancement of their professional skills and abilities for normal, irregular and critical operation of energy equipment due to their learning obtained close to real object control. Didactic hardware and software systems, correctness of interface integration and usage of technical and physical mathematical patterns like “power facility, environment , operator” as well as complete set of information and ergonomics make this software tool a real top-drawer among the similar ones.

As we know, computer control systems (CCS) (1, 5) and modern SCADA-systems are widely used for automatization of technological and production procedures by enterprises. So, the process of industrial staff training should include the following steps: (1) introduction of current state of automatization tools to trainees; (2) advancing of practical skills for working with CCS. In order to reach these aims the training methodology in the form of computer trainer is being created (6, 7). In our case we speak about the methodology that helps the operating staff control technological process of in-situ uranium leaching. This methodology is the basis for virtual trainer application (VTA) with the following main targets to be reached: (1) computer training of operating staff that work with major subsystems of workflow control systems automation (WCSA); (2) advancing effective skills of operating staff for safe and effective operation by recovery and analysis of regular, irregular and critical operating modes.

The model of VTA is introduced in the next part of this paper.

2. Model specification

2.1. General qualities

As the main goal of any industrial enterprise is an efficient manufacture administration that is achieved by streamlining of the working process, the “In-situ leaching of uranium” VTA organizational chart should correspond to this requirement by its structure and interrelations.

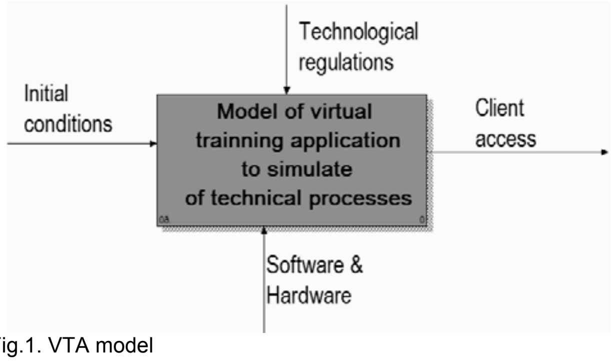

Fig.1. VTA model

Generally, the management of each enterprise regulates the services and approves staff job profiles. These factors are the basis for the set of VTA functions. We devote the present paper mainly to “In-situ leaching of uranium” VTA and offer appropriate software solutions that may be applied by the management for manufacture organization. The VTA operational control is managed by virtual training instructor. The staff working mode is 8 hours a day.

The following technical servicing and repair is possible when using "In-situ leaching of uranium" virtual training application:

1. PC and equipment renewal;
2. Malfunctioning blocks defining, repair and after-repair software launching;
3. Day-to-day equipment maintenance;
4. Adjustment and maintenance.

Operating staff that works with “In-situ leaching of uranium” VTA must be a profound PC user and complete a training course arranged by the VTA vendor. Staff job profile should contain the operating staff aims based on software operational documentation.

As the training courses are devoted to the software technical maintenance skills and basis of its operation, the operating staff should get the following post-training knowledge:

1. VTA types of servers;
2. Real-time databases;
3. Used computing tasks;
4. VTA user workstations;
5. VTA software;
6. Industrial networks.

Both the system administrator and the instructor shall act as operational managers and must know the types of servers used for VTA as well as the “In-situ leaching of uranium” VTA software.

High-level hardware operating system with the appropriate editors, loaders, system services (1, 2, 3), database operation system (4), drivers for low-level hardware (5), SCADA for data processing systems design, control and styling of user workstations interfaces (6) as well as MatLab application package used for modeling of technological parameters of the real object in the lower level of the trainer (7, 8) are the main features of the software that can be applied when it is necessary to adjust the organizational structure as well as an inference for “In-situ leaching of uranium” VTA operation.

Constant operation and correct metering required for ordinary work of “In-situ leaching of uranium” (9-13) VTA main and auxiliary equipment is provided by the instructor and system administrator for the learning purposes. These allow getting effective training results. Figure 2 below demonstrates interrelation of subsystems in the virtual learning system.

Trainer’s instructor:

1. Maintains VTA control and training using the server;
2. Observes appropriate staff training using VTA;
3. Stats up the VTA;
4. Assists to avoid property petty losses;
5. Exerts a network administrator at emergency.

Trainer’s administrator is responsible for:

1. Trouble-free software work;
2. VTA software and hardware proper work;
3. saving and keeping operational papers on magnetic carries and in hard copies;
4. appropriate VTA application;
5. resetting the whole software or its part.

2.2. System layout

There are two types of simulation represented in the Figure 5 below:

1. Darcy Law underground filtration simulation;
2. Control system hardware simulation.

When we speak about real uranium in-situ leaching process, we mean uranium ore speed of filtration, mining conductors’ saturation rate in the uranium ledge [13, 14]. The VTA allows imitating completely of these processes in dynamics. For this purpose the pattern of in-situ leaching of cellular ledge is introduced. The first block of the Figure 5, a. demonstrates the process of Darcy Law underground filtration.

Further on, the trainee needs to understand the uranium physical and chemical properties, equipment and sensory devices characteristics during the operation. The second block of the Figure 5, b. demonstrates the process hardware operation. Imitation accuracy is controlled by Matlab / Simulink-based mathematical modelling.

MatLab applied in the VTA is responsible for:

1. physical, chemical and other systems simulations;
2. geotechnical units simulation;
3. simulation of gate regulator operation when filling conductors into the barrow;
4. simulation of pump’s operation when evacuating conductors from the barrow;
5. testing equipment simulation;
6. incorporation with visualization system.

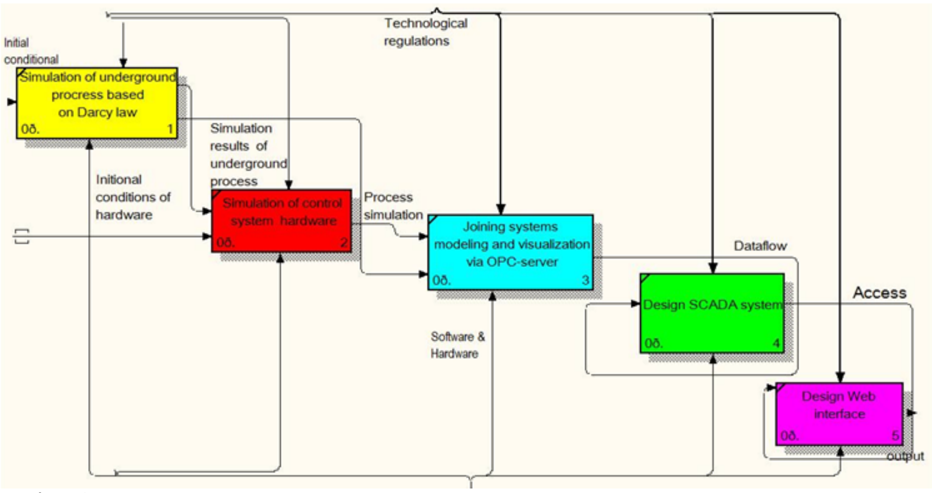

Fig.2. Virtual learning subsystems

The automatization hardware works using the deterministic mathematical models introduced by Laplace recounted dispatching activities [3, 9]. Using of command lag elements for every single hardware device allows the hardware imitate the real-time processes.

Server-Client principal is the basis for network operation. Computer of the trainer instructor performs Server functions with administrator permission. Client is represented by the computer of the trainee. The main functions of the system presented by the Figure 5c scheme are (1) uniting of modelling and visualization system by OPC-server; (2) session initialization of technological control object.

Internal software logic signals and common global variables are applied for internal interrelation of software elements. Distributed system of data capturing and routing provide intersystem connections. Output-input devices perform the function of data connector between the visualization system and operator technologist.

Trainee's and trainer's PCs are integrated into the single system by Ethernet with TCP/IP protocols.

3. Subsystem of Intellectual control virtual training

Neural networks have emerged as an important tool to model and diagnose problems in complex manufacturing process. There are many types of neural networks to map the complex relationship between input and output through supervised training algorithms, such as associate memory networks, feed-forward multilayer perceptron and radial basis functions.

There are many advantages to neural networks. First, they are data-driven self- adaptive methods that adjust themselves to the data without any explicit specification of functional or distributional form for the underlying model. Second, they are universal functional approximators because neural networks can approximate any function with arbitrary accuracy. Third, they are non-linear models, which makes them flexible in modelling real-world complex relationships. Finally, they can classify input patterns to an acceptable level of accuracy even if they were never used during the training stage through their generation ability (19).

Among them, multilayer perceptron is more suitable to our research because of its learning and generation ability.

In addition to the weighted inputs to the neuron, a bias is included in order to shift the space of non-linearity. Although there are several types of activation functions, sigmoidal functions are the most commonly used.

Figure 3 demonstrates the structure of the neuron with sigmoid output. The data from the input neurons are propagated through the networks via the interconnections to every neuron in adjacent layers. It is the structure of the input layer, hidden layers and output layer that essentially define the topology of an multilayer perceptron neural network. Each interconnection is associated with the scalar weight that acts to modify the strength of the signal. The neurons within hidden layer perform two tasks: they sum the weighted inputs to the neuron and then pass the resulting summation through a non-linear activation function (18).

This subsystem is based on artificial neural network algorithm which allows virtual trainings to complicate the task as the user experience (learner). This model provides an adequate assessment for each student individually, monitor the performance of training, as well.

Neural network architecture that provides a level of complexity sample represented as a multilayer perceptron (9, 10, 11).

The output signal is given by the expression

$$(1)\quad y(t) = f\left(\sum_{i=0}^{n} w_i(t) x_i(t)\right).$$

where $x_i(t)$ – the values are applied to inputs (synapses) of the neuron; $w_i(t)$ – synapse weight, which can be both inhibitory and augmentative; $y(t)$ – the output neuron.

Q error measure is defined as the square of the difference between the reference value and the value obtained at the output of a neuron, i.e.:

$$(2)\quad Q(w) = \frac{1}{2}\left[d - f\left(\sum_{i=0}^{n} w_i x_i\right)\right]^2$$

Just learning to use the rule of steepest descent, but now must take into account the activation function. The weights of the neuron are modified according to the expression

$$(3)\quad w_i(t+1) = w_i(t) - \eta \frac{\partial Q(w_i)}{\partial w_i}$$

where the symbol denotes the so-called *learning* rate. Is selected in the range from 0 to 1.

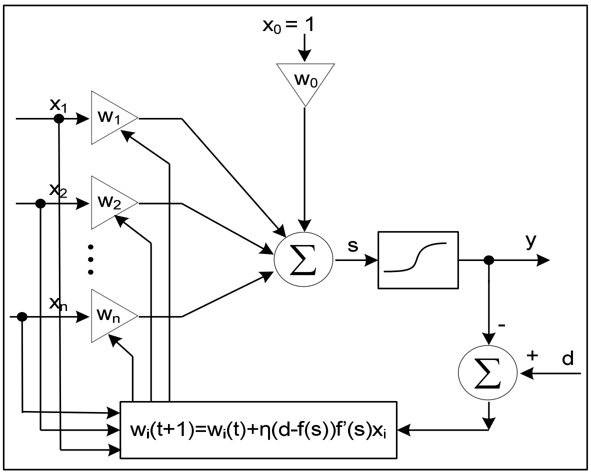

Fig.3. The structure of the neuron with sigmoid output: η – learning rate; d – reference signal; s – the output of the linear part of the neuron

Structuring a complex problem into relatively self-contained processing modules makes system easier to act which makes systems more resilient to software and hardware error than a single, monolithic module(10). Developing VTA s is a difficult undertaking and is seen as followings:

– Real-time responses during the human-system interaction;
– Adaptive task planning to meet the needs of each individual trainee based on his / her proficiency;
– Intelligent online tutoring.

Neural network architecture that provides a level of complexity sample represented as a multilayer perceptron, Figure 4.

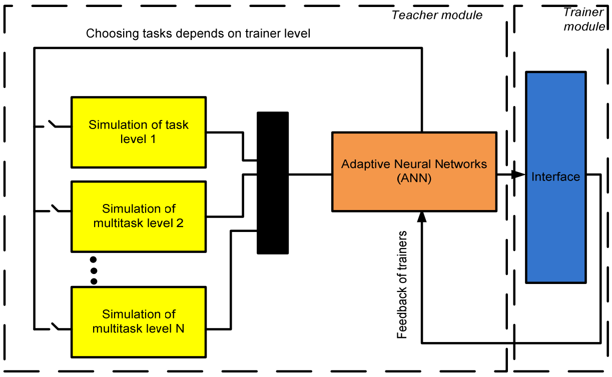

Fig.4. Neural network architecture

Subsystem of Neural Network Feedback

In any tutoring system, it is important to consider not only how feedback is given to the learner but also when it is most useful. In the proposed system, the learner has options to choose when feedback is provided. By recording the various diagnoses made during the learner's problem solving activities, the system can evaluate the learner's learning not only based on the present state of the exercise, but considering also the process through which the present state is reached. The feedback mechanism provides a means of controlling the type of feedback provided to the learner. In contrast to the immediate feedback that the system intervenes after each error made by the learner, the final feedback that is given only at the end of the exercise without considering the intermediate steps may cause the learner makes significant errors before there is any intervention. The learner who needs more frequent feedback is most likely to be one who needs more learning exercise for certain learning content. The feedback diagnosis performs an analysis of the learner's answer by calculating the semantic closeness between the learner's answer and the correct one.

The process represented by Figure 5d scheme discovers the SCADA (16) software model. SCADA systems are widely used in a variety of applications starting from climate control and finishing with nuclear plant management as SCADA software is very much convenient for running and monitoring processes. SCADA is able to operate in open and non-proprietary protocols. SCADA is even more user-friendly as it can be implemented as whole software or it can be split into parts based on the particular purposes. This principle works both with small and large systems. And the last great advantage of SCADA software is its simple configuration for almost any application without developing of custom-designed software.

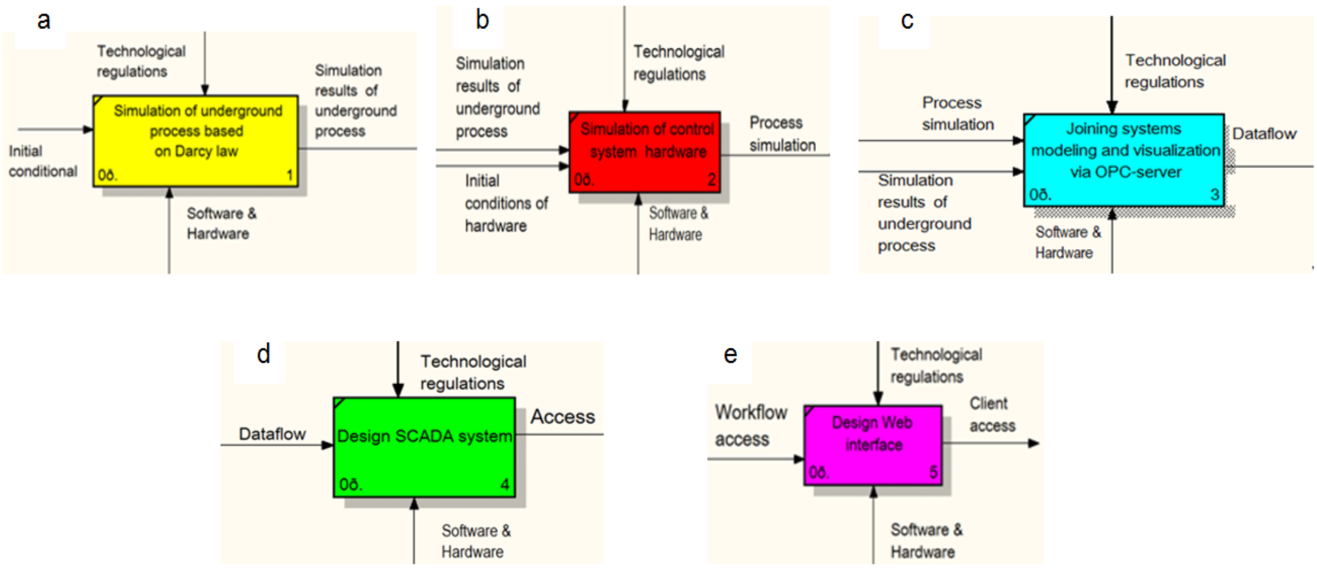

Fig.5. System layout (a) Simulation of underground process based on Darcy Law; (b) Simulation of control system hardware; (c) Joining the modeling and visualization systems through OPC-server; (d) Design SCADA system; (e) Design Web interface

The main SCADA functions are:

1. Electronic and hardware data entity collection and display;
2. User's authority and access control;
3. Modelling of acquiring, processing, analyzing, visualizing, recording and archiving data systems transmitted through measuring channels from sensors and computational means;
4. User's workplace interfaces modelling;
5. Control algorithms programming.

As the software has been designed using the dispatcher's influence on the automotive control, it is able to record this influence.

The fifth block of Figure 5e introduces Web interface design operation. The advantage of the web interface is that it can use a wide variety of web-browsers like Firefox, Google Chrome, Opera, Internet Explorer and others that offers the user a real-time Object Linking and Embedding for Process Control (OPC) applications. Web interface mode will install all the necessary applications suitable for HMI/SCADA from a centralized Web server for automatic installation to any computer running any browser. Moreover, the user can get a worldwide access to training of various modelled critical situation of in-situ leaching process and SCADA functions, like controlling, manufacturing, and process monitoring. The training results and web-sessions of the users will be resorted in the system and this makes the installation and export of the software to every personal PC unnecessary. Web-interface is going to implement this function with the help of Human Machine Interface (HMI) standard components, based on ActiveX technology. So, we may conclude that web browser will be changed into Object Processing Client (OPC) application as soon as web browser registers the web pages from any web interface server.

Conclusions

Nowadays each leading enterprise is interested in training of their employees in order to improve and perfect their professional skills. The training method using the software products is the most modern and actual one. This sort of training can give knowledge on how to act in the ordinary or critical situations by using close-to-life experience and without interruption of operational processes.

The virtual trainer application model proposed by us in this paper offers the users a simulation of in-situ leaching process and its technological environment using web services. It also offers the user theoretical and practical knowledge on how to behave in critical and non-regular cases that might interfere into normal process. The proposed VTA operates based on SCADA, mathematic modeling instruments, as role "trainer" is used adaptive neural network, which will determine the complexity of the exercise objectives. The presented VTA is an example of an integration of web technologies into educational process. The findings and results of the presented paper can be applied at the further research of technological processes simulating.

***Authors**: Prof. Bakhyt K. Mukhanov, Dept. of Automation and Control, K.I. Satpaev Kazakh National Research Technical University, Almaty, Kazakhstan, E-mail: bmukhanov@verbulak.com; Prof. Waldemar Wójcik, Lublin University of Technology, Lublin, Poland, E-mail: waldemar.wojcik@pollub.pl; Ph.D. Zhanar Zh. Omirbekova, Dept. of Automation and Control, Almaty University of Power Engineering & Telecommunications Almaty, Kazakhstan, E-mail: zhanomir@gmail.com; M.Sc. Yerbol Zh. Orakbayev, Dept. of Automation and Control, K.I. Satpaev Kazakh National Research Technical University, Almaty, Kazakhstan, E-mail: orakbaev_erbol@mail.ru.*

REFERENCES

[1] Mukhanov B.K., Omirbekova Zh.Zh., Usenov K.A., Wójcik W., Simulating In-situ Leaching Process Using COMSOL Multiphysics, *INTL – International Journal of Electronics and Telecommunications*, 2014, Vol. 60, 3, 213–217

[2] Tamosaitis R., Simulation of technological processes using knowledge-based sequences. *25th International Symposium on Automation and Robotics in Construction,* 2008, 670–675

[3] Mukhanov B.K., Usenov A.K., Omirbekova Zh.Zh., Process of in-situ leaching modeling in a Comsol Multiphysics environment., *2nd International Virtual Conference on Advanced Scientific Results*, 2014, 499–503

[4] Mukhanov B., Omirbekova Zh., Alimanova M., Jumadilova S., Kozhamzharova D., Baimuratov O., A model of virtual training application for simulation of technological processes. *Procedia Computer Science*, 2015, Vol. 56, 177–182

[5] Lisunets N.L., Smirnov O.M., Tsepin M.A., Simulation of the processes of aluminum alloys preforms and semi-finished products manufacture under influence of technological heredity and phase transitions, *Physical and Numerical Simulation of Materials Processing*, 2008, Vol. 575-578, 1134–1138

[6] Kim Y.S, Kim H.M., Design of a New Virtual Interaction Based PLC Training Using Virtual Sensors and Actuators: System and Its Application. *International Journal of Distributed Sensor Networks*, 2013, Vol. 2013.

[7] Bommer P.M., Schechter R.S, Mathematical modeling of in-situ uranium leaching, *Society of Petroleum Engineers Journal*, 1979, 19, 34-45

[8] Schechter S., Bommer P.M., Optimization of uranium leach mining, *Society of Petroleum Engineers Journal*, 1982, 22, 133–141

[9] Kabir M.I., Lake L.W., Schechter R.S, Evaluation of one-well uranium leaching test restoration, *Society of Petroleum Engineers Journal,* 1982., 22., 43–56

[10] G. Hinton, Vinyals O., Dean J., Distilling the Knowledge in a Neural Network, *NIPS 2014 Deep Learn. Work*, 2015, 1–9

[11] Walsh M.P., Schechter R.S., Humenick M.J., Hill A.D., Silberberg I.H., A Model For Predicting The Restoration Of And Ammonium Migration From In Situ Mine Sites., AIME, 1978, 248–312

[12] Kabir M.I., Lake L.W., A minifield test of in situ uranium leaching. *In Unknown Host Publication Title*, New York, 1994, 43–67

[13] Yazikov V.G., Zabaznov V.L., Petrov NN, Rogov E.I., Rogov A.E., Geotehnologiya urana na mestorozhdeniyah Kazahstana, 2001

[14] Kurth D.J., Schmidt R.D., Computer modeling of five-spot well pattern fluid flow during in situ uranium leaching. Washington: US Bureau of Mines, 1978

[15] Kurth D.J., Schmidt R.D., Computer modeling of fluid flow during production and environmental restoration phases of in situ uranium leaching, Washington: US Bureau of Mines, 1978

[16] Sandu F., Moga H., Talaba P., Stanca A.C., Online educational platform for experiment-based training and updating of SCADA operators. *Applied and Theoretical Electricity (ICATE)*, 2012, 1–7

[17] Mashkov V., Smolarz A., Lytvynenko V., Development Issues In Algorithms for System Level Self-Diagnosis, *Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska*, 2016, Vol. 6, 26–28

[18] Joung-souk S., Doo-hun L., Adaptive Tutoring and Training System Based on Intelligent Agent, *International Journal of Multimedia and Ubiquitous Engineering*, 2006, Vol. 1, 3, 6–11

[19] Dongfeng S.H., Fugee T., Modelling and diagnosis of feedback-controlled processes using dynamic PCA and neural networks, *INT. J. PROD. RES.*, 2003, Vol. 41, 2, 365–379