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THE SOFTWARE IMPLEMENTATION FOR AUTOMATIC GENERATION OF PETRI NETS

Gurskiy A. A. – PhD, Associate Professor of the Department of Technological Processes Automation and Robot-technical Systems, Odesa National University of Technology, Odesa, Ukraine.

Dubna S. M. – Lecturer of the Department of Technological Processes Automation and Robot-technical Systems, Odesa National University of Technology, Odesa, Ukraine.

ABSTRACT

Context. The important task was solved during this scientific research related to specific development and verification of the fundamental suitability of the software application that provides visualization of the automatic synthesis of Petri nets while setting up the multi-level control systems. This task is current because the for the first time the integration of means of discrete-continuous networks from the DC-Net environment in the Labview environment is realized through the implementation of automatic synthesis of Petri nets. This makes it possible to automate the processes of synthesis for the control algorithms based on the development of appropriate intelligent systems.

Objective. The purpose of the scientific work is to minimize the time and to automatize process in synthesis of the control algorithms by integrating the means of discrete-continuous networks and implementing the principles of automatic synthesis of Petri nets.

Method. This scientific article proposes the principle for automatic formation of Petri nets based on logical algorithm for classifying various uncorrected algorithms. The multilayer neural network in the Labview 2009 software environment was implemented to realize the appropriate algorithm. This artificial neural network provides algorithm formation, automatic synthesis and operation of Petri nets. The article is devoted to the study of operating principle of the software application implementing such automatic synthesis of Petri nets while setting up the multi-level control systems.

Results. A number of experiments were performed on the classification of algorithms and formation of Petri nets based on the ready-made software application. The control system was automatically set up based on the Labview 2009 environment application for the determined object.

As a result of these experiments we have determined the fundamental suitability of the software application for the synthesis of some multi-level automatic control systems. It was also shown during these experiments that all mismatch signals in the system and deviations from the ratios of values controlled variables are reduced to zero. All parameters of the control systems settings were noted after the multi-level system setting procedure on the front panel of the virtual stand.

Conclusions. The task related to the software application development based on the Labview 2009 environment which provides the automatic synthesis of Petri nets was solved in this scientific work. Thus the method of automatic synthesis of Petri nets and technology for developing certain algorithms based on the functioning of the artificial neural network was further developed.

KEYWORDS: Petri net, artificial neural network, coordinating automatic control system, coordination of transient processes, ratio control, algorithms of setting.

ABBREVIATIONS

NN is a neural network;

PN is a Petri net.

NOMENCLATURE

$A0i+$ is a *i*-th the uncorrected algorithms, where *i*=1…4;

$\varphi(t)$ is a deviation from ratio of variables;

$e(t)$ is a deviation of the controlled variable from the set value with in time;

J is an integral criterion of system;

u_1, % is a control action on the flow of cooling water on the condenser;

u_2, % is a control action linked to the speed of rotation of the compressor shaft of the refrigeration plant;

A^T is a coefficient matrix;

p is a differential operators;

$G_{x.a}$ is a compressor capacity;

P_k is a condensation pressure;

b is a constant;

x_1, x_3, x_4 are input variables for determination of the initial algorithm control;

α is a weighting coefficient in the integral criterion of system;

t'_i is a *i*-th transition in a petit network, where i=1…10;

p_i is a *i*-th position in the Petri net, where *i*=1…10;

w_{ij} is a coefficient of interneuronal connection of the *i*-th neuron of the *j*-th layer.

INTRODUCTION

Petri nets are the mathematical apparatus for discrete systems modeling. It was presented by Carl Petri in 1962 and it has many extensions nowadays. Despite this, there are few software tools to implement the synthesis of Petri nets. The well-known MATLAB software environment also does not have the appropriate tools for the synthesis and analysis of networks. Instead there is StateFlow software module that is implemented based on MATLAB for graphical representation of the finite state machine as the states diagrams. The DC-Net program has the significant difference compared with MATLAB/Simulink/StateFlow in the principle of constructing models in the complex systems [1]. The DC-Net software environment is specialized in the field of analysis and synthesis in hybrid or logical-dynamic systems [2–4]. It is possible to imagine quite visually the synthesis of Petri nets and the development of logical-dynamic models using this environment.

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Research has shown that DC-Net tools can be integrated with other software products. Thus, this research work represents the integration of DC-Net tools to implement automatic synthesis of Petri nets and to form of algorithms and sequential calculations. Automatic synthesis of Petri nets and the formation of algorithms are advisable for some tasks in the field of intelligent technologies. In a special case it could be the formation of setting algorithms for the synthesis of complex multi-level automatic control systems with subordinate control processes.

The object of study is the processes of automatic synthesis of Petri nets while setting up the coordinating automatic control systems.

The subject of study is the methods of automatic synthesis of Petri nets while setting up the coordinating automatic control systems.

The purpose of the scientific work is to minimize the time and to automatize process in synthesis of the control algorithms by integrating means of the discrete-continuous networks and implementation of the principles for automatic synthesis of Petri nets.

1 PROBLEM STATEMENT

To achieve this purpose it is necessary to solve the problem associated with the development and verification of the fundamental suitability for a software application that provides visualization of the automatic synthesis of Petri nets while setting up multi-level automatic control systems. In this case, the developed software application for setting of the multilevel control systems is acceptable if it allows to determine all the values of the k_{ij} parameters of various levels for the control system. These k_{ij} parameters of setting must give the minimum value of J integral criterion in the multilevel system. The integral criterion is

$$J = \int_0^\infty (\alpha \cdot [|e(t)/e_{\max}|] + |\varphi(t)/\varphi_{\max}|) dt . \qquad (1)$$

where α is coefficient indicating the temporal coordination of the control processes; $\varphi(t) = A^T \cdot \overline{X} + b$ is deviations from the ratio of the values of regulated variables; A^T is a coefficient matrix; b is a constant; $\varphi_{\max} = x_{1\max} \cdot k - x_{2\min} + b$ is maximum deviations from the ratio of the values of regulated variables; $e(t)$ is the deviation of some variable in time from the given value; $\overline{X} = [x_{1C} \quad x_{2C}]^T$ is controlled variables vector; $x_{1\max}, x_{2\min}$ are the maximum and minimum values of the control variables.

If $0.3 < \alpha < 0.7$, then it is possible to obtain the subordination of the control processes and to establish the fundamental suitability in order to implement appropriate control algorithm A0*i*+, where *i*=1...4. This setting algorithm is presented during the synthesis of a Petri net based on the appropriate software application. In this case, the practical implementation for automatic synthesis of Petri nets is possible through software. This software is capable of providing visualization of the Petri net synthesis process, as well as graphical programming of Petri net synthesis and analysis algorithms. In such case, it is necessary to use the means of discrete-continuous networks of the DC-Net environment to represent hybrid systems or systems with a logical-dynamic nature of functioning [5].

Currently, there is no integration of discrete-continuous networks tools into software products for implementing the synthesis of appropriate complex systems.

Consequently, the task was determined to integrate various software tools for developing complex systems while expanding Petri nets and development of the means for discrete-continuous networks of the DC-Net environment was determined. In the particular case these systems which provide the implementation for automatic synthesis of Petri nets based on the Labview environment. For our research the Labview platform was chosen along with such tools as MATLAB, C++ builder, Flash ets.

Undoubtedly, the integration of the capabilities for various software tools MATLAB, Flash, DC-Net gives obvious results, however, Labview in this case is intended for specialists with programming experience in this field activity. The Labview environment has a specific graphical programming apparatus and its own visualization platform.

Thus, the task about integrating of the means for discrete-continuous networks is relevant if we can use the graphical programming language for the appropriate environment to implement the automatic synthesis of Petri nets. It should also be noted that the Labview environment is integrated with various automation hardware in order to create measurement laboratories and different virtual stands.

2 REVIEW OF THE LITERATURE

One of the first mentioned ideas about the automatic synthesis of Petri nets was in the work of J. Peterson [6]. It was noted in this work that “the use of Petri net languages would be in the specification and automatic synthesis of Petri nets. If the behavior which is desired can be specified as a language, than it may be possible to automatically synthesize a Petri net whose language is the specified language. This Petri net can be used as a controller, guaranteeing that all and only the sequences specified are possible”.

Since then, a number of scientific articles related to the automatic synthesis and generation of Petri nets have appeared [7–10]. These scientific works reflect the principles for synthesis of Petri nets based on the rules of composition for individual subnets.

It was proposed to generate automatically Petri nets based on the functioning of the artificial neural network in such scientific works [11–13]. This artificial neural network provides the necessary composition of Petri nets and the intelligent technology for generating algorithms. This automatic composition of Petri nets was implemented primarily in order to form algorithms for the step-by-step setting of multi-level automatic control systems.

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The proposed integration of software tools was able to identify the direction linked to the software implementation of automatic synthesis of Petri nets [14–16]. This primarily applies the software integration of DC-Net with visualization tools on the Flash platform. We have found out that the integration of the mathematical apparatus for discrete-continuous networks of the DC-Net environment into the Labview environment is possible through the implementation of automatic synthesis of Petri nets. Thus, it was determined the path of development for automatic synthesis of Petri nets based on software implementation using the Labview environment.

3 MATERIALS AND METHODS

The synthesis of Petri nets is performed according to the relevant rules and can be implemented using software. The proposed synthesis of Petri nets based on the functioning of artificial neural networks is also the software implementation of synthesis in an automatic way. In this case, the neural network provides classification of algorithms and their adjustment to the given task. And this neural network is realized in software.

The formation of a Petri net when classifying various uncorrected A01+, A02+, A03+, A04 algorithms can be represented on the basis of a logical classification algorithm representing a binary tree [17 – 18]. In this case we have different logical classification algorithms; one of the simplest algorithms is shown in Figure 1. In such a tree the predicate is prescribed at each vertex $\beta_i : X \to \{0;\ 1\}$. It should be noted here that the algorithm may include various x_4, α, γ variables and linguistic rules for generating the appropriate result $\beta(x_4, \alpha, \gamma)$.

If we consider the classification of setting algorithms and the functioning of coordinating automatic control system, then $\beta(x_1) = 1$ when selecting logical control algorithm which provides the sequential inclusion of control loops in operation, $\beta(x_3) = 1$ when setting up the control system in a step-by-step mode, $\beta(x_4, \alpha, \gamma) = 1$ when setting up the system on the structural-temporal subordination of control processes.

The multi-layer neural network was implemented in the Labview 2009 software environment using graphical programming tools in order to implement the appropriate algorithm. This artificial neural network provides classification of algorithms, automatic synthesis and operation of Petri nets.

The generated Petri net represents a step-by-step algorithm for setting up the multi-level automatic control system that provides the separation of motions mode [13, 19]. Thus, the control system is synthesized and also provided a coordinated change of the controlled variables in transient modes.

The process of generating Petri net and the setting up process of the control system are visualized on the front panel on the virtual stand. This front panel of the stand is shown in Figure 2. The process of Petri net synthesis is presented as the result of the composition $PN_1 ... PN_m$ individual networks. The front panel shows a number of $PN_1 ... PN_m$ individual Petri nets that can represent the functioning of individual elements for the system being developed.

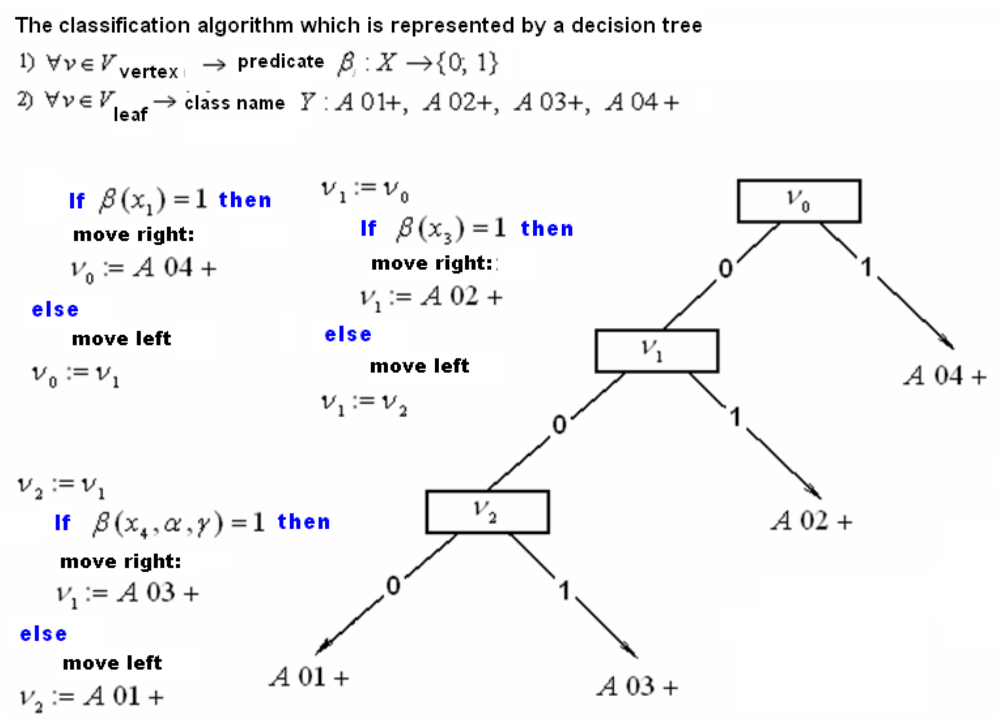

Figure 1 – The logical classification algorithm

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It is also presented on the front panel such items:

– the automatically generated Petri net as a result of the classification by *A*01+, *A*02+, *A*03+, *A*04 various algorithms;

– the markings of Petri net;

– the errors displayed at various stages of system operation;

– the values of control system settings parameters.

At the initial stage of operation in this software application we have set the certain parameters of the control object and the ratio coefficients between the controlled variables that we need to coordinate.

After that we can select a task from the various options, such as:

– step-by-step system setting;

– setting to separation of motions mode;

– the control logical.

We also can select the algorithm of step-by-step actions or the algorithm of parallel operation. Petri net is formed as a result of choosing the appropriate task and algorithm. This Petri net is formed as a result of the composition of individual Petri nets, which are presented on the front panel of the stand (Fig. 3).

After the Petri net has been formed, it starts its functioning. The artificial neural network interacts with the $PN_1...PN_m$ Petri nets, and the process of the synthesized Petri net is visualized (Fig. 4). As a result of the movement of markers in the Petri net, changes are made to the settings of the coordinating control system. If deviations from the predetermined ratio between the regulated variables are reduced to zero then a certain transition in the Petri net is triggered to perform the next stage of system setting. Thus, the Petri net demonstrates the setting of the control system. The operator only makes sure that at all transitions of the Petri net there are no errors when setting up the system.

Ultimately, the system setup will have been completed while appearing the marker in position p_{10}.

The formation of Petri net is implemented as a result of classification of algorithms and their adjustment if errors are noted at certain stages while operating the synthesized Petri net. One can see in Fig. 5 the *NN* multilayer neural network in the fragment of the front panel of the virtual stand. This multilayer neural network operates on the principles of feedback with $PN_1...PN_m$ separate Petri nets. However, wherein it is ensured the synchronous movement of markers in $PN_1...PN_m$ Petri nets linked with an *NN* artificial neural network.

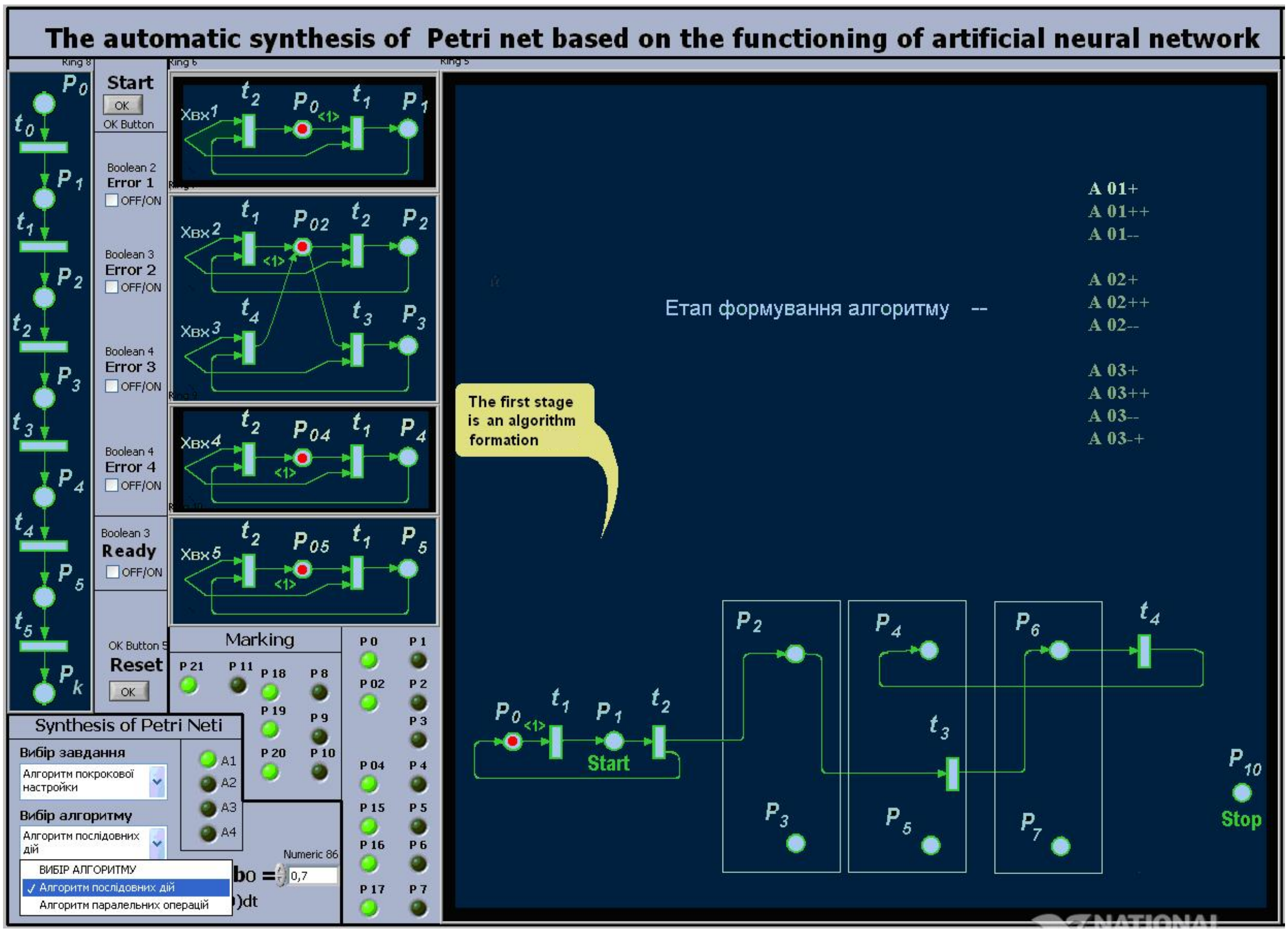

Figure 2 – Front panel of the virtual stand demonstrating the automatic formation of a Petri net as a result of classification of various algorithms

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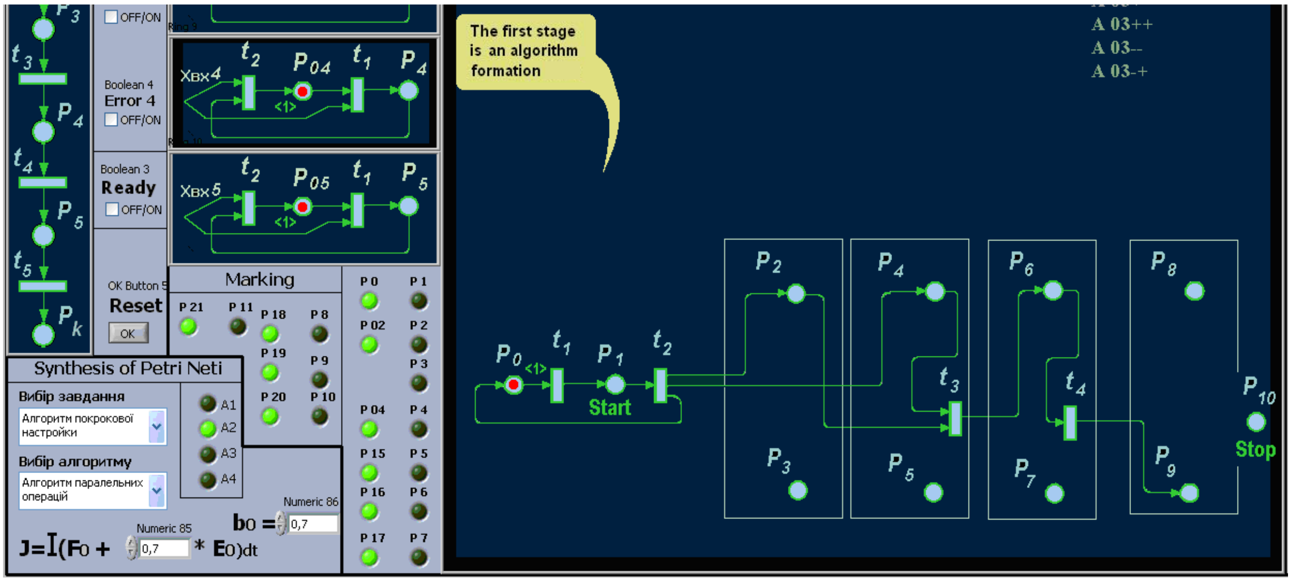

Figure 3 – Front panel of the virtual stand demonstrating the generated Petri net

One can perform the composition of a Petri net during the synchronous changes in the markings in Petri nets. In a particular case, this composition will represent an algorithm for step-by-step configuration of a multi-level control system. It is shown that each position of the generated Petri net matches a specific position of the PN_i Petri net connected to the *NN* neural network. The t'_2 and t'_1 transitions covered by the dotted curve are combined into t_2 transition and so on according to the diagram of the generated Petri net. This is shown in Fig. 5.

4 EXPERIMENTS

A number of experiments were conducted based on the finished software application. A number of experiments were performed by classification of algorithms as well as the formation and correction of Petri nets. The parameters of a certain control object were also specified, for which control systems were automatically implemented based on the Labview 2009 environment. A refrigeration turbocompressor was chosen as the object. To improve the operating efficiency of a turbocharger, we need to coordinate changes in the shaft rotation speed and the cooling water flow rate on the condenser when regulating the boiling pressure. The appropriate block diagram of the customizable control system is presented as seen from the Fig. 4. According to the diagram, we have represented the system control law in the following way: $\bar{u} = \bar{u}_q + \bar{u}_p = [u_1 \quad u_2]^T$, where: $\bar{u}_q = [u_{q1} \quad u_{q2}]^T$ is the control vector of the 1st level; $u_1 = u_{q1} = k_1 \cdot (1 + k_{11} \cdot {}^1\!/_p) \cdot \varphi(t)$;

$u_{q2} = k_2 \cdot (1 + k_{21} \cdot {}^1\!/_p) \cdot \varphi(t)$; $u_2 = u_{q2} + u_{p2}$

$u_{p2} = \Delta P_{kip} \cdot k_3 (1 + k_{31} \cdot {}^1\!/_p + k_{32}\, p)$ is the law of 2nd level of control; $\varphi(t) = k_1 \cdot G_{x.a} - p_k + b$; ΔP_{kip} is a deviation of the controlled variable from the set value; k_1, k_{11}, k_2, k_{21}, k_3, k_{31}, k_{32} are parameters that are determined in the process of step-by-step setting according to the generated Petri net. These parameters are determined in this way that the integral indicator has a minimum value.

We have also carried out the system optimization in MATLAB/Simulink 5.2 in order to assess the quality of system settings. All parameters in the model of control object and in the appropriate control system which was set we have also shown in Fig. 6. The comparative analysis of the experimental results has been performed using the MATLAB environment.

5 RESULTS

The fundamental suitability of the software application for the synthesis of some multi-level automatic control systems was established as a result of the experiments. After carrying out the procedures for setting up a multi-level system, all the control system setup parameters were presented on the front panel of the virtual stand and it was also shown that all mismatch signals in the system and deviations from the ratio of the values of the controlled variables were reduced to zero. Signals of mismatch and deviation from the given ratio were reduced to zero both during the step-by-step setting up of a multi-level system and when sequentially connecting the control loops into operation. However, the most important thing is that the developed software application has demonstrated the principle for automatic synthesis of Petri nets based on the logical classification algorithm. In the particular case it was demonstrated the automatic synthesis of Petri nets in the formation of algorithms for setting up multi-level automatic control systems.

It was also established the possibility for automatic generation of Petri nets based on the reachability tree. Such a generated Petri net will represent a logical control algorithm ensuring the sequential connection of the control loops for a multi-level system to operation.

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The experimental results are presented in Table 1. All these data from Table 1 were obtained as a result of simulation in the MATLAB/Simulink 5.2 software environment. Based on the data presented in the table we can determine the fundamental suitability of the developed software application for setting control systems.

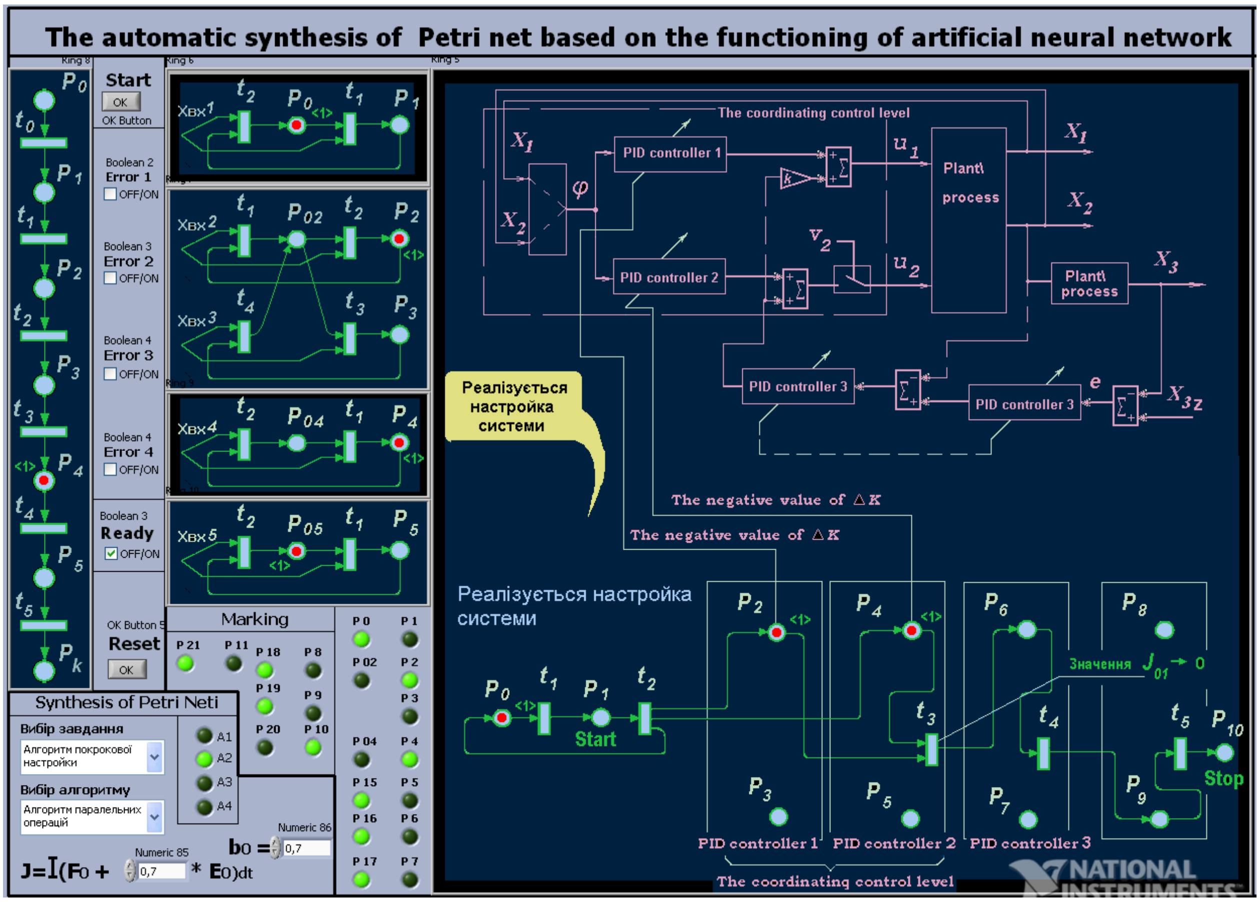

Figure 4 – The front panel of the virtual stand displaying the setting up process of the automatic control system according to the generated Petri net

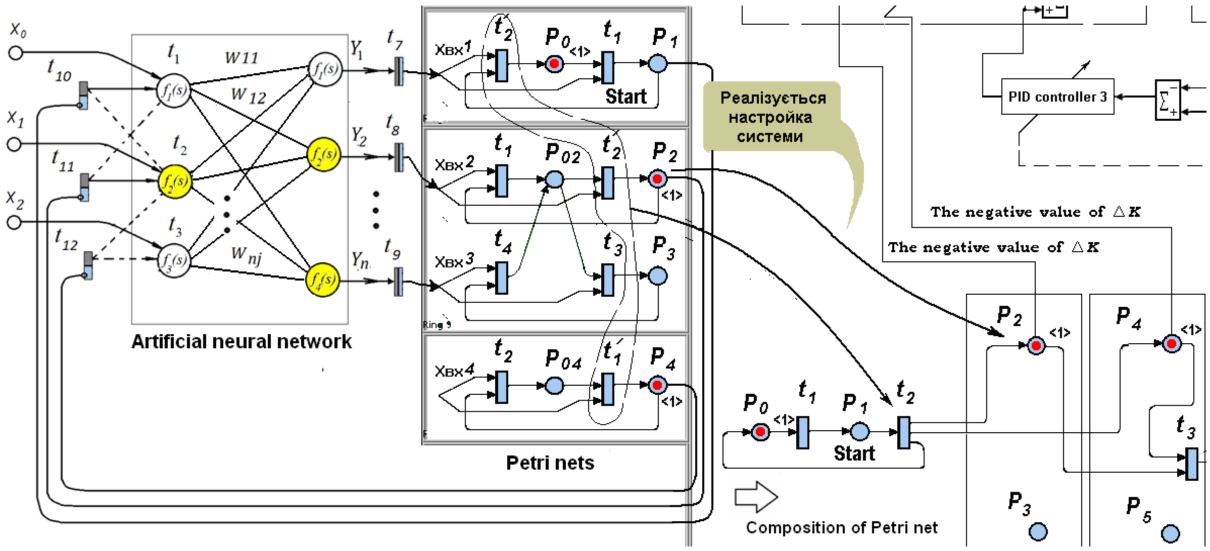

Figure 5 – Schematic diagram for the synthesis of an artificial neural network and Petri nets for the formation of appropriate logical control algorithms, $w_{11}, \ldots w_{nj}$ is coefficients of interneuron connections;
$t_7, \ldots t_{12}$ is discrete-continuous transitions providing the communication between an artificial neural network and Petri nets

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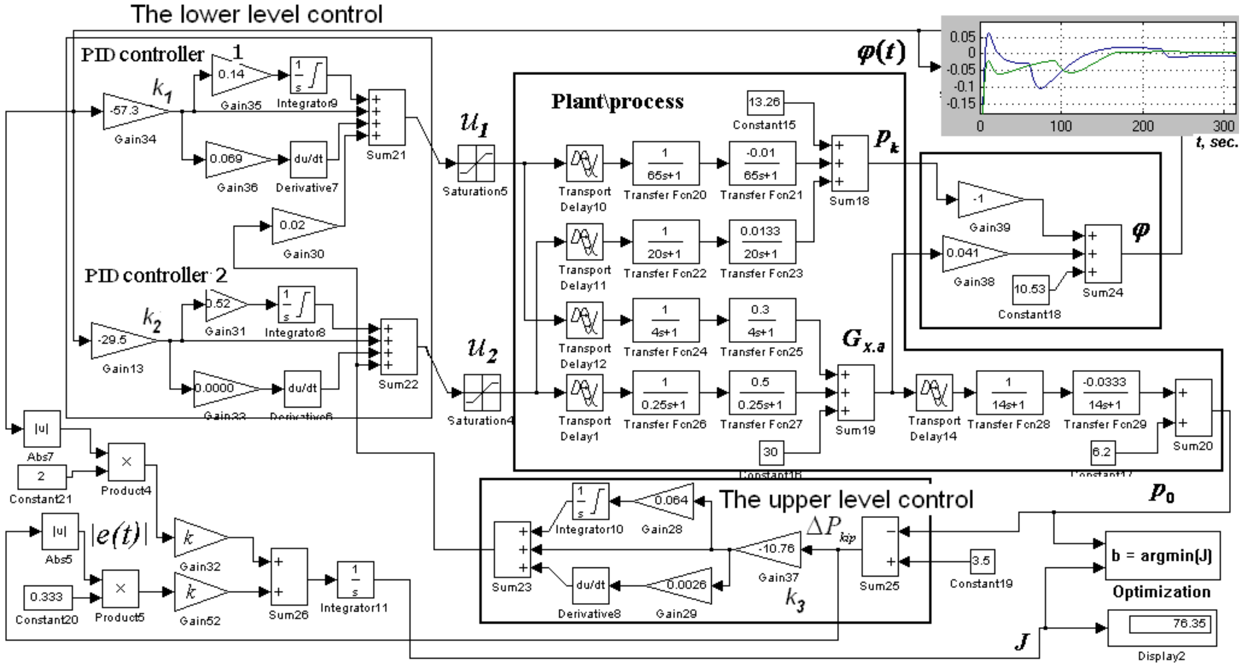

Figure 6 – Block diagram of the model of the coordinating automatic control system presented by means of the MATLAB \ Simulink software environment

Table 1 –Values of the J integral indicator for the quality of system functioning after setting and optimization based on software

	Setting for separation of motions mode at $\alpha = 0.3$	Setting for separation of motions mode at $\alpha = 0.7$	Step-by-step system setting at $\alpha = 1$
Setting in the application based on the Labview environment	45.32	98.7	115.36
Optimization in the MATLAB/Simulink 5.2 framework.	36.4	81	87

Transient processes of the optimized and set systems in different software environments are also presented in Fig. 6. Such obtained graphs allow to evaluate the quality for setting of system.

6 DISCUSSION

The setting program of systems for the subordination of control processes we can compare with an analogue of the optimizer program based on the MATLAB/Simulink 5.2 environment. Comparing the data from Table 1, we can draw the appropriate conclusion. The difference in the values of the integral indicator for different systems is small. However, it is obvious that the quality indicators of the system have become better after optimization in the MATLAB/Simulink environment. In order to assess the fundamental suitability of the presented software application we also need to synthesize on its basis a number of control systems for the various objects of automatic control not only in the field of refrigeration equipment. Further expansion of the software application should be directly related to an increase in the dimension of the multilayer artificial neural network, which is implemented in software with elements of the initial training (Fig. 5).

This expansion is quite important, since in such a system any operator action is associated with the work of an artificial neural network, which represents an intelligent technology for automated configuration of the multi-level control system. This automated setting has a significant difference from similar synthesis and optimization using the MATLAB/Simulink environment. In a particular case during operation of the control object we able to rebuild the system in order to provide subordination of regulatory processes.

CONCLUSIONS

The scientific novelty of the results. The problem associated with the development of a software application providing automatic synthesis of Petri nets was solved in the present work. This software application was developed based on Labview 2009 environment for setting up multi-level control systems. Thus the design technique of automatic synthesis of Petri nets based on a logical classification algorithm has got the further development.

The practical significance of the results. The developed software application has practical importance. The Labview 2009 software environment is integrated with the various software and hardware automation of laboratory research and technological processes.

The prospects for further research. Further development of the scientific direction should be directly related to the formation of methods for training of neural networks which we can use in the developed software application.

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ПРОГРАМНА РЕАЛІЗАЦІЯ АВТОМАТИЧНОЇ ГЕНЕРАЦІЇ МЕРЕЖ ПЕТРІ

Гурський О. О. – канд. техн. наук, доцент кафедри автоматизації технологічних процесів і робототехнічних систем інституту комп’ютерних систем і технологій «Індустрія 4.0» ім. П.Н. Платонова Одеського національного технологічного університету, Одеса, Україна.

Дубна С. М. – старший викладач кафедри автоматизації технологічних процесів і робототехнічних систем інституту комп’ютерних систем і технологій «Індустрія 4.0» ім. П. Н. Платонова Одеського національного технологічного університету, Одеса, Україна.

АНОТАЦІЯ

Актуальність. Вирішено актуальне завдання, що пов’язане з розробкою та перевіркою на принципову придатність програмного додатку, який представляє візуалізацію автоматичного синтезу мереж Петрі при налаштуванні багаторівневих систем управління. Таке завдання є актуальним, оскільки вперше реалізується інтеграція засобів дискретно-безперервних мереж середовища DC-Net у середовище Labview за рахунок реалізації автоматичного синтезу мереж Петрі. Це дає можливість автоматизувати процеси синтезу алгоритмів управління на основі розробки відповідних інтелектуальних систем.

Мета роботи – мінімізація часу та автоматизація процесу синтезу алгоритмів управління за рахунок інтеграції засобів дискретно-безперервних мереж та реалізації принципів автоматичного синтезу мереж Петрі.

Метод. Запропоновано принцип автоматичного формування мереж Петрі на основі логічного алгоритму класифікації різних нескоригованих алгоритмів. Для реалізації відповідного алгоритму, в програмному середовищі Labview 2009 за допо-

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могою засобів графічного програмування було реалізовано багатошарову штучну нейронну мережу, на основі якої забезпечується формування алгоритмів, автоматичний синтез та функціонування мереж Петрі. Показано принцип роботи програмного додатку, що реалізує такий автоматичний синтез мереж Петрі при налаштуванні багаторівневих систем управління.

Результати. На основі вже готового програмного додатку було проведено ряд експериментів з класифікації алгоритмів, формування та коригування мереж Петрі. Були задані також параметри деякого об'єкта управління, для якого були автоматично налаштовані системи управління на базі середовища Labview 2009. В результаті проведених експериментів було встановлено принципову придатність програмного додатку для синтезу деяких багаторівневих автоматичних систем управління. Після проведення процедур налаштування відповідної багаторівневої системи на лицьовій панелі віртуального стенду відзначалися всі параметри налаштування системи керування, а також було показано, що всі сигнали неузгодженості в системі та відхилення від співвідношення значень регульованих змінних зведені до нуля.

Висновки. Таким чином, у роботі було вирішено завдання, пов'язане з розробкою програмного забезпечення, на основі середовища Labview 2009, що реалізує автоматичний синтез мереж Петрі. Тим самим отримала подальший розвиток методика автоматичного синтезу мереж Петрі та технологія розробки певних алгоритмів на основі функціонування штучних нейронних мереж.

КЛЮЧОВІ СЛОВА: мережа Петрі, штучна нейронна мережа, координувальна система автоматичного управляння, узгодження перехідних процесів, регулювання співвідношення, алгоритм настройки.

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