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Design of intelligent component of hierarchical control system

I. Tsmots[1], M. Medykovskyy[1,2], A. Skorokhoda[1], T. Teslyuk[1]

[1] Lviv Polytechnic National University; e-mail: taras.teslyuk@gmail.com
[2] Department of Telecommunications, University of Computer Sciences and Skills, Poland, Lodz
e-mail: medykmo@gmail.com

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Abstract. One of the main tasks of modern hierarchical systems management are integration of technological, organizational and economic management functions and processes. Another important task is creation of unified information space with accurate, complete and current information. Efficient hierarchical systems management requires intelligent processing of large amounts of heterogeneous information. It is appropriate to process information via intelligent components that are built using artificial neural networks. Strategic information about macroenvironments, microenvironments and internal environments are the input data for intelligent components of upper management levels. Intelligent components may solve different tasks which could have features like: large amount of data, data diversity (quantitative, qualitative, text), contradiction and incomplete data, consistency and high intensity of incoming data, high computing amount with dominance of computing operations over logical operations, recursions and regularity of data processing using neural network algorithms, continuous complications of processing algorithms and increasing requirements for results accuracy, possibility to process data in parallel. The method of synchronized spatio-temporal mapping algorithms for intelligent operation component that provides synchronization of data flow intensity with computing intensity (hardware implementation) and takes into account the processor architecture (software implementation) has been designed. It has been proposed to use following principles: conveyor and spatial parallelism in data processing, modularity, specialization, uniformity and regularity of the structure, programmability architecture. during design of intelligent hardware components. Evaluation of structure of intelligence hardware components carried out using test equipment efficiency. Equipment efficiency takes into account number of interface outputs and number of interneuron connections. At the next step it links performance costs of equipment and evaluates elements by device performance. The method for designing of intelligent component management system that uses synchronized spatio-temporal mapping algorithm has been described. Current method takes into account the components, the requirements of the specific application and provides implementation of intelligent components with high efficiency.

Key words: design, energy efficiency, intellectualization of control systems, assessment, prediction.

INTRODUCTION

The major goals of the modern hierarchical control systems are that of integrating control functions of technological, business processes, creating a unified information space with reliable, comprehensive and latest data. The effective operation of the hierarchical control systems requires intelligent processing of a large amount of information of different types. It is advisable to carry out such kind of processing in the modern hierarchical control systems through the use of intelligent components. These are built by using artificial neural networks. The strategic information about macro- and microenvironment along with an internal environment of an enterprise represents input data for the intelligent components of upper management levels. These components are used to boost management efficiency of financial, business, administrative activities and manufacturing. At the lower levels of management, input data for the intelligent components is the information about the state of manufacturing process and data received from sensors. The results obtained at the outputs of the intelligent components are used to produce signals for managing sensors, actuators, apparatuses and units [1, 2].

The main problem of designing the intelligent components of the hierarchical control systems is as follows [1–5]:

- formulating the requirements and choosing means of implementation (software, hardware or both software and hardware),
- choosing a neural network architecture corresponding to the problem to be solved,
- forming a learning test sample and selecting a learning algorithm,
- designing highly efficient intelligent components.

In relation to this, the issue of developing highly efficient intelligent components of hierarchical control systems becomes of special relevance.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

In recent years, there have been a lot of researches and publications dealing with the issue of management at all levels of a hierarchy – from manufacturing processes to the governance of financial, business and administrative activities. One can consider the most important of these publications.

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Challenges arising at the highest levels of management, including planning of resources and materials, are discussed in great detail in [6]. The drawback of this work is that it paid little attention to the development of the intelligent components using artificial neural networks.

Not only books but also separate articles have examined resource planning. In particular, although all of the aspects of this theme have been covered in [7], it pays little attention to the problem of intellectualization of data processing. The researches carried out in [8–9] are of great importance. Their authors have demonstrated that for the effective support of business functions and business processes, the systems should be integrated with other information systems.

In the work [10], an attempt was made to summarize the latest developments in the field of production planning. Nonetheless, it lacks attention on use of the neural network technology. Control means of industrial processes are covered in [11–13]. The feature of these methods is that they focus on the use of cloud-based technologies.

The works [14–17] consider the issue of developing those components that control manufacturing processes. There is a lack of attention on the intellectualization of sensors and data processing in these studies.

LEVELS OF HIERATCHICAL MANAGEMENT

The control systems with a hierarchical or multilevel structure have been used most widely. A hierarchy is the location of parts and components in order from highest to lowest. Thus in the systems with such a structure, control functions are divided into units or subdivisions of various levels or ranks. A managing body of some hierarchical level manages several lower-level units under its authority and itself is controlled by a higher-level organ. Modern enterprise management systems have mostly four-level structures.

The first management level involves the management of financial, business and administrative activities. At this level of management, planning and analysis of manufacturing activity of an organization is performed by using the following software IRP (Intelligent Resource Planning), ERP (Enterprise Resource Planning) and MRP (Material Requirements Planning).

The second level of management controls the manufacturing processes with the use of the MES (Manufacturing Execution Systems) software for synchronization, coordination, analysis and optimization of products.

The third level represents control and operation of a manufacturing process. To solve these problems, the SCADA system is used. Its main function is to create an operator’s interface and collect data on manufacturing. For controlling and handling the manufacturing process, a software tool is utilized, which is an assembly of devices, communication channels and algorithmic-based software. Programming logical controllers (PLC) are used as equipment, in which the operating system represents programming utilities for these controllers or PC-like controllers with the built-in DOS systems. This level exhibits the use of the intelligent tools of data processing, devices of visual control and manufacturing process performance. Preprocessing and intelligent data processing are done in the controllers. The control and operation systems use, as the PLC, a wide nomenclature of devices both of domestic and foreign manufacturers, which are able to process per unit time from a few to hundreds of variables.

The fourth level represents touch sensors (primary transducers), actuators, microcontroller-based systems for gathering information and controlling assemblies, apparatuses, installations and actuators. At this level primary information is obtained by using the touch sensors. Based on the processing of this information, the signals are generated to control assemblies, apparatuses, installations and actuators. This level of management is characterized by using the PLC and the DCS (Distributed Control System) software.

At each of the four levels, information is supplied in parallel and, if possibly, processed in parallel. Managers can also take decisions either in parallel to or independently from each other.

LEVELS OF HIERATCHICAL

Defining problems for the intelligent components of the hierarchical control systems. The use of the intelligent components in the hierarchical control systems ensures greater management efficiency of manufacturing processes, industrial, financial, business and administrative operations of the company. At each level of management, there are objectives focused on implementation in terms of the intelligent components.

For the intelligent components of the first and second management levels, there is a following rough list of problems:

- financial forecasting (nonlinear forecasting of financial data while predicting the stock market and forecasting the state of the market),
- detection and reduction of a fraud level (credit cards, transactions, etc.),
- modeling and control of the enterprises’ performance,
- segmentation and market clustering, which provides an analysis of immense amount of data without human intervention, and proves to work well together with automated data collection (which is popular among online surveys, etc),
- data mining and business analytics,
- visualization of multidimensional data,
- decision support systems,
- management by weak signals allows an organization to increase flexibility reserve beforehand to avoid the risks at their early stages of occurrence,
- credit scores when approving loans and calculating credit ratings, credit risk assessment based on data about a client,
- valuation and value prediction of property, getting quality information about various factors that potential buyers of real-estate prefer,

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- evaluation of staff while selecting applicants for the job (a forecast of future results of a candidate's performance based on his/her biographical data),
- information security of computer systems.

For the intelligent components of the third and fourth management levels, there is a following rough list of problems:

- preprocessing and estimation of data from sensors under conditions of hindrance and incomplete information,
- operation of actuators and complex objects,
- processing of video streams, recognition of images and scenes in vision systems,
- traffic management, traction control and supporting services in vehicles,
- autonomous control and traffic forecast,
- prediction and control of manufacturing processes and complex objects,
- load balancing of electricity networks for work optimization,
- optimization of resources costs and operating modes of industrial systems,
- setting parameters according to the environmental conditions.

FORMULATING REQUIREMENTS FOR THE INTELLIGENT COMPONENTS OF THE HIERARCHICAL CONTROL SYSTEM

The first and second management levels of an enterprise are characterized by accumulation of huge amount of information about various aspects of its activities, the dynamics of its development, the history of interaction with different suppliers, partners and customers. The intelligent analysis of this information through the use of neural networks, genetic algorithms, neuro-fuzzy logic allows one to gain knowledge, based on which the future performance of the enterprise can be predicted, and potential threats or opportunities identified.

The third and fourth management levels are concerned with the control of manufacturing processes and with a direct operation of assemblies, apparatuses, installations and actuators. The intelligent components of the third and fourth levels are applied to solve these problems:

- preprocessing and estimation of data from sensors under conditions of hindrance and incomplete information,
- operation of actuators and complex objects,
- processing of video streams, recognition of images and scenes in vision systems,
- prediction and control of manufacturing processes and complex objects,
- optimization of resources costs and operating modes of industrial systems,
- setting parameters according to the environmental conditions.

The implementation of the IACS (integrated automated control system) intelligent components is proposed to be done on the basis of artificial neural networks. The main problem of using artificial neural networks for implementation of the IACS intelligent components lies in the selection of necessary input data for a specific problem, choosing a neural network architecture corresponding to the problem, forming a test sample for testing a neural network and selecting a test algorithm. Typically, the strategic information about macro- and microenvironment along with an internal environment of an enterprise represents input data for the intelligent components of the first and second levels of management. The third and fourth levels represent information from sensors, apparatuses, assemblies and actuators. At the output of the intelligent components of the first and second management levels signals are generated, based on which management decisions are made. The output of the intelligent components of the third and fourth management levels generates control signals for actuators, apparatuses and assemblies [1–3].

The analysis of the main problems that are solved by the intelligent components of the control system shows that the considerable part of applications involves processing of intensive data streams in real time through means that satisfies the constraints on dimension, power consumption and cost. In particular, these problems include the ones to be solved at the third and fourth levels of management.

The features of problems solved by the intelligent components of the control system are as follows:

- enormous amount of data,
- data heterogeneity (quantitative, qualitative, text-based),
- contradictory and incomplete data,
- invariability and high intensity of input data arrival,
- large amount of computations with computing operations outnumbering logical operations,
- regularity and recursiveness of neural network algorithms for data processing,
- constant complication of algorithms for processing and increasing requirements for accuracy of results,
- parallelization of data processing both in time and in space.

One of the most common requirements imposed on the intelligent components of the control systems is to ensure their high performance.

As a rule the same problem occurs when using the IACS intelligent components for problem-solving situations in real time that puts certain constraints on data processing [1–3]. To ensure processing of data flows in real time, the hardware performance should be:

$$\Pi \geq \frac{R b F_d K_d n_k}{N n_d}, \quad (1)$$

where: R – means the algorithmic complexity for solving problems, b – a coefficient that considers implementation means of the algorithm, F_d – denotes the frequency of incoming data, K_d – a number of channels of incoming data, n_k – number of bits of incoming data

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channels, N – a value of input data set, n_d – number of input data bits.

The use of the intelligent components in the third and fourth levels of management with equipment located close to the sensors and actuators puts tight constraints on their weight and size characteristics. At the same time such devices are imposed by strict requirements for power consumption affecting a size of power sources as well as devices of heat transfer. These requirements can be met by reducing the length of a bit grid, using fixed-point operands, minimizing a list of commands together with a number of address lines that determine the memory capacity available for a user. Furthermore, the intelligent components of the control systems have to ensure high survivability, reliability, performance check and rapid fault localization. The problem of high survivability of the intelligent components arises when they are utilized in the control systems by specifically responsible objects located at a large distance from a person or objects of high external effect. For high survivability of the intelligent components, its structural parts are to be interchangeable.

A weight and size reduction as well as the reduction of energy consumption, the increase in reliability of the intelligent components and real-time operation could be achieved through the use of state-of-the-art integrated technologies and very-large-scale integrated circuits (VLSI).

ANALYZING TYPES OF IMPLEMENTATION OF INTELLIGENT COMPONENTS

For the development of the intelligent components of the control systems we will use artificial neural networks. The main problem of using the artificial neural networks is that there is a need to select input data for solving a problem specified, choose a neural network architecture corresponding to this problem, form a test sample for testing the neural network and select a test algorithm. The artificial neural network with multiple inputs and outputs is designed to convert input signals into output signals. Typically, the strategic information about macro- and microenvironment along with an internal environment of an enterprise represents input data of the intelligent components of the first and second levels of management. The third and fourth levels represent information from sensors, apparatuses, assemblies and actuators. At the output of the intelligent components of the first and second management levels we obtain information that is used for decision making. The output of the intelligent components of the third and fourth levels generates control signals for actuators, apparatuses and units [2].

From the set of existing types of implementation of the intelligent components of the control system, we will examine the following:

- software type uses the universal CPU (Central Processing Unit) and graphic GPU (Graphics Processing Unit) processors, allows the development of dedicated software for them,
- software – hardware type deploys a universal compute core, aimed at tasks of neural network processing and is supplemented by specialized hardware and software tools that implement basic neural network algorithms and operations,
- hardware type shows how the architecture and arrangement of a computational process within it represent a structure of the operation algorithm of an intelligent component.

The first type is available to the general public. Its distinct advantage is that it allows for using previously developed programs. The disadvantage of this type is, however, low speed, functional and structural redundancy of computer tools. This type is designed for implementation of the intelligent components at the first and second levels of management.

The second type is a union of general-purpose and special-purpose tools. Interpenetration of general-purpose into specialized, hardware into software ensures a high efficiency of equipment utilization as well as data processing in real time. When it comes to this approach, the development of software and hardware with given technical parameters supplements a computing core with the necessary special-purpose hardware components.

The third hardware type focuses on the processing of intensive data flows by using complicated algorithms. The principal advantage of this type is in ensuring high performance. Besides its high performance, the hardware type has the following disadvantages:

- dedicated hardware is developed for performing only specific tasks,
- enormous equipment costs for their implementation,
- high cost of hardware and time-consuming development of specialized tools.

The second and third types are used to implement the intelligent components of the third and fourth levels of management with the feature to operate in real time.

THE METHODS OF SYNCHRONIZED SPATIO-TEMPORAL REPRESENTATION OF OPERATION ALGORITHMS OF THE INTELLIGENT COMPONENTS

For the development of the intelligent components of the control systems, there is a need in spatio-temporal representation for their operation algorithms treated with a different degree of detail, which is determined by means of implementation. Upon implementation of algorithms in a programmable manner, for their representation, it is advisable to use operations that are effectively performed by CPU and GPU processors. Representing algorithms at a level of elementary arithmetic operations is applicable in the hardware implementation by using custom and semi-custom VLSIs. The spatio-temporal rendering of the algorithm must detect all types of parallelism and find necessary solutions both in time and space for its effective implementation. The multi-tier parallel structure (MTPS) of algorithm rendering meets the above mentioned requirements. While the MTPS is used for an expression of the algorithm, all its functional operators Φ_i are distributed by levels in a way so that the j-th level

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contains those functional operators that depend at least on one functional operator at the (*j-1*)-th level and are independent of the operators at subsequent levels. All functional operators of the same level are to be performed independently.

Each *j*-th level of the algorithm is expressed by the following parameters:

- sets of independent functional operators Φ_{ji}, where j denotes a level number, i is a number of a functional operator at the level,
- set of channels of data arrival and generation of intermediate results,
- number of bits for each channel.

In the MTPS algorithm the number of levels means its height h, and the maximum number of functional operators at a level determines its width L. With the use of spatio-temporal factors, the position of functional operators in a space-time coordinate system is specified. Such a representation of a directed graph we will call a flow parallel form or a flow graph [3, 18]. The parameters of the flow graph such as the complexity of functional operators Φ_{ji}, the width L and the height h are mutually dependent. A change in one of the parameters introduces changes in all the parameters.

In order to transform a functional graph into a flow graph, it is necessary to write the former as a matrix $n \times n$, where "*1*" denotes the presence of a communication channel, "*0*" means its absence [3]. The matrix is arranged so that each functional operator Φ_{ji} of information source has a string representing its connection with other functional operators. If relevant columns of matrix are specified through vectors $\vec{V}_{\Phi 1},...,\vec{V}_{\Phi n}$, one can define the resultant vector:

$$\vec{V}_0 = \vec{V}_{\Phi 1} + \vec{V}_{\Phi 2} + ... + \vec{V}_{\Phi n}. \quad (2)$$

In vector $\vec{V}_0$, we can determine the number of elements that equal zero, for example, the second element and the fifth one. The functional operators are found by just defined numbers having no descendants and, therefore, forming a zero level, Φ_2 and Φ_5 in this case. Then we calculate by the formula:

$$\vec{V}_1 = \vec{V}_0 - \vec{V}_{\Phi 2} - \vec{V}_{\Phi 5}. \quad (3)$$

In vector $\vec{V}_1$, we find the numbers of zero elements that can be used to define those functional operators that form the first level. Similarly we calculate successive vectors and define the functional operators that form the following levels.

For an effective implementation of the operation algorithms for the intelligent components, it is proposed to represent the algorithms mentioned as a synchronized flow graph. This type of graph has been devised in four stages:

1) decomposing the operation algorithm of the intelligent component,
2) designing communications (data exchange) between functional operators,
3) consolidating the functional operators,
4) planning of computations while implementing the algorithm.

At a stage of decomposition, the operation algorithm of the intelligent components Φ is to be broken into functional operators Φ_{ji}, between which connections are established that correspond to this algorithm. Decomposition can be treated by the method of functional decomposition. Using a method of functional decomposition allows a structure of the operation algorithm for an intelligent component to be represented both in space and time with a required degree of detail. The first stage of the development has resulted in a graph-scheme algorithm, where the functional operators Φ_{ji} have approximately the same runtime, and their complexity is determined by means of implementation.

At the stage of communications design, it is necessary to define a structure and a number of bit channels of data exchange between the functional operators Φ_{ji} For this reason, the graph-scheme algorithm is transformed into a flow graph, in which the functional operator Φ_{ji} are located at space-time points and fixed to the tiers. The structure of connections in a flow graph between the functional operators Φ_{ji} of neighboring tiers is determined by the number of channels of incoming data and the number of bits.

Upon two stages of development, the flow graph ensures:

- evaluation of the computational complexity of the algorithm and defines the required performance of the universal CPU and graphic GPU processors during the software implementation of the intelligent component,
- choice of user-defined macros for software and hardware to be hardware-implemented,
- evaluation of data processing intensity for the hardware implementation of the flow graph of the operation algorithm for the intelligent component.

Here are output data for defining the data processing intensity for the hardware implementation of the flow graph of the operation algorithm for the intelligent component:

- number of channels of data arrival s and their number of bits n,
- complexity of functional operators Φ_{ji} and high performance of hardware components, specifying pipeline cycles T_k of equipment operation.

The intensity of data processing during the hardware implementation of a flow graph can be defined as:

$$D_{\kappa-a} = \frac{sn_s}{T_\kappa}. \quad (4)$$

The data processing by the intelligent component in real time requires synchronization of data arrival intensity

$$P_d = kn_k F_d,$$

where: k – denotes a number of channels of incoming data, n_k – a number of bits of data channels, F_d – means the frequency of data arrival with the intensity of data

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processing D_{k-a}. To evaluate the synchronization of the data arrival intensity P_d with the computational capability D_{k-a}, one introduces a coefficient of synchronization which is given by:

$$L = \left\lceil \frac{P_d}{D_{\kappa-a}} \right\rceil, \quad (5)$$

where: $\lceil \ \rceil$ – means a sign of rounding to a greater whole number.

The synchronization coefficient L can be $L=1$, $L>1$ and $L<1$.When $L=1$, then the devised graph of the operation algorithm for the intelligent component is synchronized, and its hardware implementation ensures the highly efficient use of equipment.

In case $L>1$, the devised graph of the operation algorithm for the intelligent component is not synchronized, and it is necessary for its coordination to increase the intensity of data processing D_{k-a}. An elevation in the intensity of data processing D_{k-a} can be achieved either by increasing the number of data sorting channels s and their number of bits n or by facilitating the complexity of functional operators Φ_{ji}. If changing the parameters under discussion has not yielded the necessary intensity of data processing D_{k-a}, then the parallel operation L of hardware components is to be used.

The third stage of development is reduced to the consolidation of operations by combining the functional operators Φ_{ji} as well as data transmission channels both within a tier and across tiers. This stage of development is utilized for the software implementation, neural-oriented and dedicated hardware implementations of the algorithm.

The software implementation of the algorithm uses a phase of consolidation to be adapted to the structure of the universal CPU and graphic GPU processors.

With the software and hardware implementation as well as just hardware implementation, the consolidation phase is applied in case when $L<1$. That is, when there is a need to reduce the intensity of data processing D_{k-a}. As a result of such integration we will receive a graph, representing the operation algorithm for the intelligent component, that we will call a concretized flow graph. The consolidation phase is closely connected with the planning stage of sorting.

The fourth stage of planning of computations is reduced to storing information about the structure of the flow graph representing the operation algorithm of the intelligent component. At this stage the computational process is performed, the values of delay factors and data permutation are determined. To reproduce the data processing in the concretized flow graph, statements of control and delay along with permutation operators are to be introduced. One can consider two possible ways for consolidating operations (integration of functional operators) in order to get a concretized flow graph of data sorting.

The first way of getting the concretized flow graph of the operation algorithm for the intelligent component is a linear projection of this graph on the horizontal axis X. In this case the consolidation of operations is performed by combining functional operations across tiers along with data transmission channels. The latter falls into a class of SIMD architecture (Single Instruction Multiple Data) processor. SIMD processors have a distinct feature of simultaneously performing the same operation to process a set of independent data. For the software implementation of the concretized flow graph of the operation algorithm for the intelligent component, it is advisable to apply a cross-platform compilation system and the CUDA platform.

The second way of getting the concretized flow graph of the operation algorithm for the intelligent component is a linear projection of this graph on the vertical axis ***Y***. In this case the consolidation of operations is performed by combining functional operations and data transmission channels both within tiers and across tiers. This kind of consolidation of operations results in the concretized flow graph allowing the synchronization of intensity of data arrival P_d from the computational capability D_{k-a}. These concretized flow graphs of the operation algorithms for the intelligent component can be hardware and software implemented as well as just hardware implemented.

THE METHODS OF DESIGNING THE INTELLIGENT COMPONENTS FOR THE CONTROL SYSTEMS

The purpose of designing the software intelligent components for the control systems is to enable CPU and GPU processors to work effectively [19, 20]. In general, the effectiveness of the software intelligent components of the control systems depends on that how the concretized flow graph of the algorithm has adapted to the architecture of CPUs and GPUs. Quantitatively the effectiveness of the software intelligent components is defined as:

$$E_n = \frac{t_{ei}}{t_{ps}}, \quad (6)$$

where: ***t*** – denotes a period of time over which the ***i***-th element of processors is occupied with useful operations, tps is a total time for solving the problem.

The purpose of designing the hardware intelligent components for the control systems is to get modular and regular structures based on VLSI technology. The output information for the synthesis of the hardware intelligent components is:

- concretized flow graph of the operation algorithm for the intelligent component,
- learning algorithm and a neural network performance,
- amount of input data N,
- data arrival intensity and weighting factors,
- interface requirements,
- number of bits of input data, weighting factors and the accuracy of computations,
- performance requirements and constraints.

The objective of designing the hardware intelligent components is to ensure their operation in real time with minimum hardware expenses [3].

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The transformation of the concretized flow graph of the operation algorithm of the intelligent component into the hardware structure is, formally, that to minimize hardware costs:

$$W_{hk} = \sum_{j=1}^{M} W_{E\Pi_j} + \sum_{i=1}^{n} W_{HEi} + k_1 Y + k_2 P, \qquad (7)$$

where: $W_{E\Pi_j}$ – means the equipment costs incurred in implementing the $j-th$ element of preprocessing, M – denotes the number of preprocessing elements, W_{HEi} – the equipment costs incurred in implementing the $i-th$ neural element, N – the number of neural elements, Y – presents the number of interface terminals, k_1 – is a coefficient that considers the number of interface terminals $k_1 = f(Y)$, P – the number of interneuronal connections, k_2 – coefficient that considers interneuronal connections $k_2 = f(P)$ provided that the following condition is fulfilled:

$$T_{ex} \geq T_{ps}, \qquad (8)$$

where: T_{ex} – denotes the time of exchange, T_{ps} – the time for solving a problem.

While designing the hardware intelligent components for the highly efficient use of equipment, one should:

- develop the operation algorithm for the intelligent component and represent it as a concretized synchronized flow graph,
- transform the concretized synchronized flow graph into the structure of hardware regarding performance characteristics and constraints,
- choose an architecture and model of a neural network as well as neural elements of preprocessing,
- develop the interface and data exchange system across the neural network's layers,
- with the flow structure of the neural network applied, determine an ordering of time implementation of a neural network's layer and synthesize the controls.

If the hardware structure of the intelligent component is selected, one should use the efficiency criterion for equipment utilization Eo, which considers the number of interface terminals, the number of interneuronal connections and associates the performance with the equipment costs, giving an estimation of elements (valves) by performance [3]. When the intelligent component is implemented with VLSI, the efficiency of equipment utilization Eo, is quantitively defined as:

$$E_o = \frac{R}{t_o(\sum_{j=1}^{M} W_{E\Pi_j} + \sum_{i=1}^{n} W_{HEi} + k_1 Y + k_2 P)}, \qquad (9)$$

where: R – denotes the complexity of operation algorithm of the intelligent component, which is determined by the number of elementary arithmetic operations required for its implementation, t_0 – to is the time of implementing the operation algorithm of the intelligent component.

The specialized hardware structure of the intelligent component must exploit the capabilities of VLSI technology to the full extent and ensure the processing of intensive information flows in real time [1 – 3]. The cost of VLSI mainly depends on the area of a crystal and the number of pins. The number of VLSI-based external pins is limited by the level of technology and the crystal size.

To use the advantages of VLSI technology to the full extent during the development of the specialized hardware intelligent components, the following principles has been proposed [3]:

- pipelining and spatial data parallelism,
- modularity,
- specialization and adaptation of the architecture of the intelligent component to the structure of algorithms as well as data arrival intensity,
- uniformity and regularity of the structure,
- programmability of the architecture by using programmable logic devices (PDSs).

The use of the principles described in the design of the hardware intelligent components will reduce cost and time spent on development. If the PLD-based intelligent component is hardware implemented, one of the software suites of hardware design is to be used (for instance, Altera Quartus II or the Xilinx ISE) [21]. By using these packages, the libraries containing totalizers, multiplying units, evaluators of scalar product, implementations of the activation functions, neurons, etc., schematic editors and one of the hardware description language (for instance, VHDL) the specialized hardware intelligent components are designed. Correctness of the performance of the component developed is done by using functional and timing modeling. The final stage of development considers the choice regarding the hardware costs, high performance and cost of a certain crystal.

CONCLUSIONS

1. It has been analyzed and shown that the advantage of the software implementation of previously developed applications can be used. The advantage of the software and hardware implementation includes the required performance achieved through adding the specialized hardware. The hardware implementation has its advantage in processing intensive data flows in real time.
2. The method of synchronized spatio-temporal representation of the operation algorithms of the intelligent component that provides the consolidation of data arrival intensity with computing intensity (hardware implementation) and considers peculiarities of a processor architecture (software implementation) has been developed.
3. The following principles like pipelining, spatial data parallelism, modularity, specialization, uniformity and regularity of the structure along with programmability of the architecture have been proposed to be applicable for the design of the hardware intelligent components.
4. For the evaluation of the hardware structure of the intelligent components, it has been proposed to use the efficiency criterion for equipment utilization, which considers the number of interface terminals, the number of interneuronal connections and associates the

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performance with the equipment costs, giving an estimation of elements of the device by performance.

5. The method of designing the intelligent components for the control systems, which uses a synchronized spatio-temporal representation of algorithms, considers the features of hardware components along with the specific application requirements and ensures the highly efficient implementation of the intelligent components, has been developed.

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