Hetero-Associative Memory Technology for Development of Intelligent Control Systems of Autonomous Mobile Robots

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***Abstract*—The problems of creating artificial intelligence technologies in the control of service robots are considered. Based on the synthesis of artificial neural networks and associative memory, a neural network model of iterative hetero-associative memory has been developed. This model is designed for recording, storing and processing sensory and control information. A neural network model of the hierarchical intellectual control system of autonomous mobile robots is proposed. This model, based on the available a priori knowledge, is able to function and adapt to changes in external conditions.**

***Keywords*—intelligence control system, autonomous mobile robot, artificial neural network, associative memory, knowledge base, OSTIS**

I. Introduction

Modern service and domestic robots must function in a dynamic human environment characterized by the uncertainty of external disturbances. This requires the involvement of non-traditional approaches to their control systems. These approaches should be based on the novel methods of knowledge bases, new types of feedbacks, modern information and telecommunication technologies. At this stage, these approaches can be combined under the common name of artificial intelligence [1].

One of the promising methods for developing intelligent control systems (ICS) can be bio-inspired. It is based on the modeling of obtaining and recognizing information processes in the nervous systems of life forms [2, 3]. Bio-inspired methods are based on the investigation of the fundamental principles of the natural control systems functioning and their evolution mechanisms. These principles determine life forms behavior, and not certain aspects of their demonstrations. In other words, bio-inspired control methods are based not so much on reference patterns classification algorithms, as on search algorithms that allow to adapt to another environmental conditions. As a rule, control systems of the life forms do not have analytical models. In addition, the necessary knowledge must be accumulate empirically during process of the control system interaction with the environment and with itself [1, 2].

Among the known methods of artificial intelligence, expert systems, artificial neural networks (ANN), associative memory and fuzzy logic can be especially highlighted [2,3]. However, to our point of view, technologies such as expert systems and fuzzy logic require the involvement of an operator (expert) in the control loop to a greater extent than the other two. Thus, ANN and associative memory are more suitable for the creation of ICS by autonomous robotic devices.

II. Artificial Neural Networks as a Units of Intelligent Control System

One of the leading directions in the field of artificial intelligence is associated with the modeling of ANNs. ANNs are able to solve a wide range of problems of image recognition, identification, prediction, optimization and control of complex objects [1, 2]. ANNs are creates on the principles of organization and functioning of their biological analogs.

Advantages of ANNs over traditional methods of artificial intelligence (production systems, decision tables, genetic algorithms, fuzzy logic, etc.) are manifested in solving problems that are characterized by problems in the allocation of rules for the functioning of systems. As a rule, such problems have a large number of possible solutions, but there is the possibility of learning on a lot of examples [4].

ANNs are also successfully used in dynamic object control systems [3,4]. ANNs have a number of unique properties that make them a powerful tool for creating control systems: the ability to learn by example, the generalization of data, the ability to adapt to changing the properties of the control object and the external environment, the suitability for the synthesis of nonlinear regulators, high resistance to damage to its elements (in force originally embedded in the ANNs parallelism) [1-5].

Thus, ANNs are convenient to use in those applications where there is no possibility of obtaining training samples from experts in a particular field. In this case, there is a process of self-organization, in which the ANNs changes its functional structure without special intervention from outside (see Figure 1). Since the process of self-organization is manifested in the fact that the ANNs independently selects samples from the input data stream for training, the choice of the ANNs model must take into account the specificity of incoming information, measuring and control means.

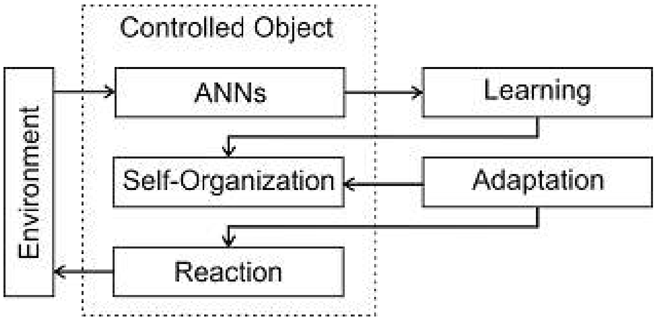

Figure 1. The adaptation process of the robot to environmental conditions through the self-organization of ANN.

Nevertheless, ANNs also have its limitations due to the lack of a universal architecture and unified approaches for use in control systems, as well as problems of additional learning of new information. At the moment in the developed control systems ANNs are used in the form of separate blocks and, mainly, only for the implementation of functions of classification or data interpolation, which significantly narrows their potential.

In special control tasks for autonomous mobile robots (AMR), ANNs are often criticized [6]. Firstly, this is due to the fact that most ANNs are not control systems, but merely imitate the recognition systems. In other words, the function "input-output" is search from some variables, and the values of the objective function of the system are specified in other variables. Secondly, most classical learning algorithms such as backward propagation errors work only in supervisory mode, that is, they are not self-learning [6]. And, finally, thirdly, similar ANNs do not work in conditions of post-training, when in the process of adding a new pattern to the trained network, the results of previous training are destroyed or changed.

III. Neural Network Model Hetero-Associative Memory for Recording, Storing and Processing of Information

On the basis of S.Grossberg adaptive resonance theory [7-10] and the ANN be-directional associative memory (BAM) [11-13] is proposed an adaptive neural network classifier ART-BAM with the retrain function. The ART-BAM classifier can be used in the autonomous mobile robot control system. With the help of the original non-iterative algorithm for new patterns detecting and the available of reference patterns in the long-term memory, the classifier ART-BAM is able to register new patterns in the sensory data stream [14]. The obtained information is used by the robot control system to generate control signals. Another important property of the developed classifier is the implementation of the learning process on the teacher mode, which allows the user to combine in one class different patterns. A model of iterative hetero-associative memory is proposed, on the basis of which the modified BAM network (ModBAM) is able to record, store and process sensory, information and control signal sequences [15]. In comparison with existing analogues, the proposed model of memory allows processing information data sequences, the length of which considerably exceeds the size of its inputs. It also has a more efficient mechanism for adding new information blocks [10 A] to memory. Based on this memory model, the following devices were proposed: a device for recording, storing and extracting binary sequences and a device for processing sensory data [15].

IV. Neural Network Model of Intelligent Hierarchical Control System of Autonomous Mobile Robots

Based on the methodology of the Pospelov's theory of natural and artificial systems behavior [16,17] and Zhdanov's method of autonomous adaptive control [6], the author proposed an original neural network model of the hierarchical ICS by autonomous mobile robots [18]. This ICS consists of conditional units of the processor and memory (Figure 2, filled blocks), which themselves consist of distributed sub-units implemented on the basis of hetero-associative ANNs. And thin arrows indicate information flows, and bold - control signals.

On the board of Controlled Object (CO) are the executive (Effectors - E) and sensory (Receptors - R) units and ICS, in the control loop which includes the operator unit. In this case, the object of control is AMR. As a rule, the Robot Operator must interact with the ICS only before the beginning of the operation of the AMR (at the time of entering the targets and the necessary initial data) or in critical situations. The ICS receives information from the external and internal environments by means of the Receptor unit and acts on the external environment by the Effector unit.

From the proposed scheme (Figure 2), it can be seen that the processor and memory units, like natural ICSs, have a distributed structure. One of the most important parts of the processor is the data preprocessing unit - the pre-processor, represented by the Pattern Formation and Recognition Units (PFR), in which information necessary for other units is extracted from the incoming data. The next part of the processor is represented by the decision making unit (DM), which controls the hierarchy of sequences of sub-goals execution.

In the proposed ICS model distributed memory is represented by a database (DB), a knowledge base (NB), a reflective unit (RE) and an Evaluation and Prediction unit (EP). The evaluation and prediction unit is responsible for cognitive functions of the ICS. The tasks of the database are not only the collection and transfer of sensory data in the Pattern Formation and Recognition unit, but also their registration (writing in parallel the values of the control signals from the effectors). This is required in order for the operator to perform a full analysis of the control decisions taken by the ICS after the AMR job is completed.

The sign ⇔ indicates the process of bidirectional information exchange that occur in the 2nd and 3rd loops as a result of the iterative way of extracting information from the knowledge base and the feedback of the memory adjustment - the process of the after-training [18].

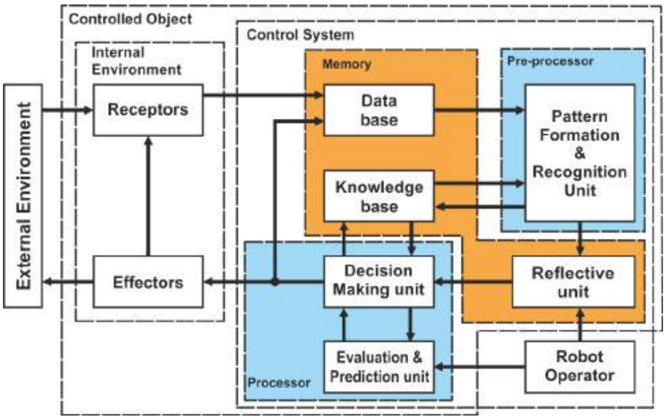

Figure 2. The main functional units of the proposed bio-inspired control systems.

Thus, three types of control loops are implemented in the proposed ICS:

1) $R \to PFR \to RE \to DM \to E$, - reactive;
2) $R \to PFR \to NB \Leftrightarrow DM \to E$, - extremum-seeking;
3) $R \to PFR \to NB \Leftrightarrow EP \to DM \to E$, - cognitive.

Unconditioned and conditioned reflexes involved in the first circuit of the proposed ICS are implemented in the RE unit in the form of two different hetero-associative ANNs, which, upon receipt of a certain stimulus, are attract a strictly fixed reaction. The reactive control loop can be implemented on the basis of the adaptive neural network controller proposed in [14], implemented as a system of rules. Thanks to the presence of hetero-associative ANNs, this controller allows to quickly extract the reference patterns from memory and process the input information, as well as add new ones to the memory.

Thus, unconditioned reflexes (i.e. "stimulus-response" learning pairs) should be recorded by the operator in the ANNs before the start of the AMR operation [14]. Conditioned reflexes should be remembered in the process of periodic external influences on the control object through the training of motoneurons ANN . This provides a mechanism for individual adaptation of the control object to small changes in the environment. Moreover, if the synaptic connections of the first ANN contain information on the critical values indicators of the energy and transport systems and must be strictly fixed, then the second - synaptic connections should have the ability to memorize the learning outcomes only for a finite time (ie, they can be retrained) . Output signals of the hetero-associative ANNs of unconditioned reflexes are passive – they affect only the control solutions of the PR unit. But signals from ANNs conditioned reflexes (motoneurons) are active, that is, they directly control the motion of the effectors. The second circuit (extremum-seeking control) is designed to implement a more complex type of behavior of the control object, which is able to recognize previously trained situations and respond to them with a corresponding sequence of actions of the effectors. In the extremum-seeking control loop, a control system must be implemented, which, with the help of experience-oriented actions, seeks to minimize certain objective functions of the control object. In other words, this circuit must implement the execution of some predefined search algorithms with branching [15].

V. Application Methodology of the Hetero-Associative Memory Technology

The neural network models, algorithms and methods proposed in this paper can find wide application in robotics and various branches of automated production. The developed model of a neural network hierarchical control system with distributed information processing [15,18] is used in the on-board control system of small-sized autonomous mobile robots. Based on the proposed neural network models and algorithms, software-hardware controls for group robots designed to solve research and research problems in conditions that are inaccessible to humans Thanks to the use and testing of the proposed neural network models for the management of mobile robots, we have gained enough practical experience. Based on this experience, TABLE 1 was created, which is intended to assist in choosing a management system to solve a particular practical problem.

Table I
Control System Selection

#	External Environ-ment	Search Algo-rithm	Control Loop	Teaching Mode	Knowledge Base
1	Simple or complex obstacles, known mapping	Random walking	Reactive	Manual control before start	Unconditi-oned reflexes
2	Simple obstacles, unknown mapping	Random walk / Objective search		Automatic / Interactive manual-automatic control	Conditi-oned reflexes
3	Complex obstacles, unknown mapping	Objective search	Extremum-seeking	Manual control before start / Interactive manual-automatic control	Branching algorithms

Table 2 shows what a positive effect the user should get when using the proposed neural network technology.

VI. Conclusions

Was realized an attempt to combine the technology of classical ANN and associative memory model based on a deterministic chaotic system into a single neural network model of memory, the ability to model not only partial manifestations of associative brain functions, but also some of the processes of exchange and processing of information, as well as the search for hidden links between existing standards in memory.

Among the main positive properties of the obtained memory model, we can distinguish the realization of information search

Table II
EFFICIENCY OF DEVELOPED TECHNOLOGY APPLICATION

#	Features	Structure	Entity	Outcome
1	Content-addressed storage	ART-BAM	Reduction of computing and energy costs	Increasing of decision making speed
2	Programming by example	ART-BAM / ModBAM	Does't require the specialist (programmer) participation	Increasing of programming speed
3	Patterns Adding / Removing	ART-BAM	Stimulus / response principles	Adaptive decision making
		ModBAM	Information block	Increasing of programming speed

by its content and storage of information in the form of structured binary sequences. It can also be noted that the process of retrieving information is a dynamic process, similar to processes occurring in various physical systems of continuous operation.

A modular neural network model of the intellectual hierarchical control system of autonomous mobile robots is developed, the modules of which are separate control loops: reactive, extremum-seeking and cognitive. On the one hand, this system has a strict hierarchical structure, consisting of three control loops. On the other hand, all calculations are performed in parallel and distributed in the corresponding functional units. The units are implemented using the proposed hetero-associative ANNs. At the moment, in the model environment, separate contours of the developed control system have been created and tested for various practical applications: the manipulator position control system, the neural network model for realizing the search motions of the autonomous mobile robot and the reactive contour of unconditioned and conditioned reflexes.

The next direction of our research will be integration of the proposed neural network models and semantic technologies of OSTIS. It is suggested that due to the universal method of representation of knowledge, OSTIS technology will effectively implement not only classical formalized knowledge bases, but also unformalized knowledge bases based on the ANNs.

Because OSTIS implemented on a remote server and can be accessed via the Internet, it is possible to control a group of autonomous mobile robots.

The work was carried out with partial financial support of the BRFFR F16P-146.

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ТЕХНОЛОГИЯ ГЕТЕРО-АССОЦИАТИВНОЙ ПАМЯТИ ДЛЯ РАЗРАБОТКИ ИНТЕЛЛЕКТУАЛЬНЫХ СИСТЕМ УПРАВЛЕНИЯ АВТОНОМНЫМИ МОБИЛЬНЫМИ РОБОТАМИ

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Рассмотрены проблемы создания технологий искусственного интеллекта в задачах управления робототехническими аппаратами. На основе синтеза двух перспективных технологий – искусственных нейронных сетей и ассоциативной памяти – разработана нейросетевая модель итерационной гетеро-ассоциативной памяти, предназначенная записи, хранения и обработки сенсорной и управляющей информации. Предложена нейросетевая модель иерархической интеллектуальной системы управления робототехническими аппаратами, которая способна на основе имеющихся априорных знаний автономно функционировать и адаптироваться к изменениям внешних условий.