An innovative approach in the study of mechatronic devices

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ABSTRACT

Innovation in industry is the organization of the principles of operation of robotic devices in accordance with the new challenges of modern times. This is due to the distortion and noise contamination of signals during the transmission of information in the control systems of robotic devices operating in conditions of uncertainty. Therefore, one of the main requirements of the industry is to build innovative robotic systems with high robustness, adaptability and stability that can adapt to any conditions. The main purpose of this work is to create a system for planning the future motion of the robot depending on the intensity of the input signals. Before discussing the methods of studying robotic devices, the article analyzes the generations of robotic devices and the process of modeling a motion planning system of third-generation robotic devices with the use of artificial intelligence.

1. Introduction

The application of artificial intelligence methods as an innovative approach to the control of robotic systems has become very widespread recently. Recent advances in modern control theory allow the implementation of intelligent methods for controlling complex technical systems (mechatronic devices, robots, etc.) operating in conditions of uncertainty. As the application of intelligent methods to mechatronic and robotic systems covers the professional and daily activities of human life, global production of equipment in this field is growing every year. Robotics is in a unique position to integrate innovations and developments that have already been tested in other areas: software, networking, smartphone manufacturing, new electronic devices, and so on. It should also be noted that today the development of the space industrial robot is far ahead of the development of the social industrial robot [1-7].

2. General problem statement

It is known that mechatronic devices, robots, robotized technological complexes are the leading trend in the development of modern industry. This trend is particularly evident in the development of intelligent robots and next-generation robotic equipment, aircraft and military equipment, as well as

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microsystems and medical equipment. The main reasons for the development and application of intelligent robots are as follows:

– freeing humans from heavy work, as well as from extreme working conditions (polluted environment, chemical environment, life-threatening, etc. environment) in the production process;

– significant increase in labor productivity in the implementation of operations in the production process;

– significant increase in the product quality;

– reduction of the cost of manufactured products.

The innovative development of robotics in the industry in terms of its functional capabilities and purpose covers three generations [1-2]. The first generation is industrial robots based on the use of automatic devices with one or more "arms". Such robots are used for efficient execution of technological and transport operations. The second-generation adaptive robots are communication sensors, i.e., robots that have a better structure to respond to changes in the environment with touch devices and vision, and adapt to changes in the external environment. This feature is the main indicator that distinguishes adaptive robots from the first-generation robots. The third-generation robots are being developed in the present era. The main difference between this generation of robots and previous generations is that it puts forward a new innovative direction — the operating mechanism of artificial intelligence robots.

It is known that artificial intelligence is a field of science that studies and models human natural intelligence. The main purpose of applying artificial intelligence to industrial robots is to make them learn (gain knowledge) in the process of active interaction with the environment and to be able to imitate various operations performed by humans in the process of mental and physical labor. The generalized functional structure of industrial robots is shown in Fig. 1.

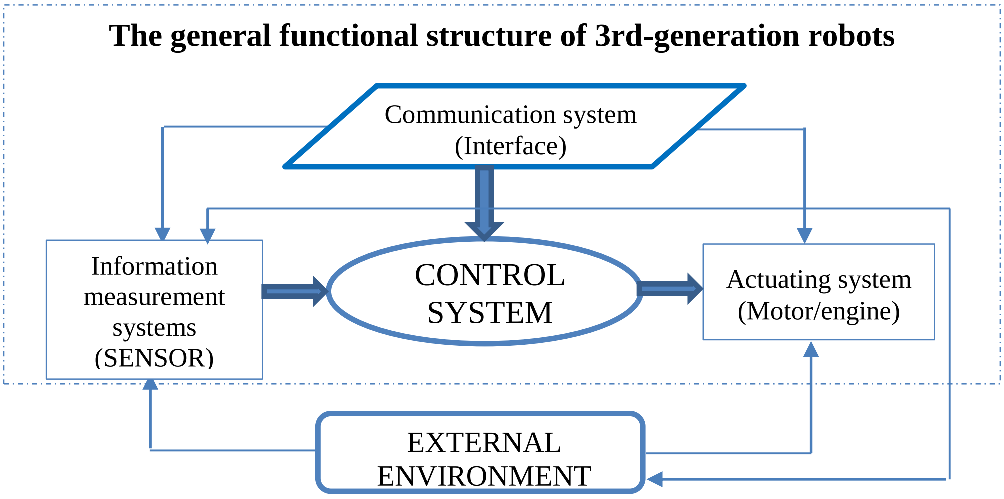

Fig. 1. The structure of 3rd-generation robots

As can be seen from Figure 1, the general structure of third-generation robots consists of 5 units: a communication system; information measurement systems (sensors); a control system; an actuating system and external environment.

Information measurement systems represent the robot's artificial sense organs. Like natural sense organs, they collect information about the state of the external environment and transmit it to the robot's control system ("brain"). The robot's brain is usually based on the computing device (computer technology) used. The robot's "motor", that is, the actuating system that determines its ability to perform various actions, serves to prepare the control signals generated by the control system and to act on the environment. Manipulators (mechanical arms) are usually used as actuating systems.

Analysis of the development of robotics shows that one of its most promising areas is the creation of robots with artificial intelligence. Relevant scientific literature discusses the problems related to the planning of purposeful behavior of intelligent robots in various aspects, the formation of the knowledge base of reflex activity. Analysis revealed that the environment in which Autonomous Mobile Robots (AMRs) operate is highly uncertain, dynamic, and covers a large number of objects of variable size and state. Under such conditions, the problem of planning the purposeful behavior of AMR by analyzing its activity on the basis of such criteria as the size of obstacles, their condition, the exact mathematical laws of motion of objects, etc. is considered relevant.

3. Solution

To solve these problems, it is advisable to apply and implement the neural network model, one of the new areas of modern control theory. The neural network model is a branch of artificial intelligence and has made great strides in object recognition and learning. To this end, synthesizing the operation of an autonomous mobile robot in this way will help the robot make decisions based on information received from vision sensors. Therefore, the set of sensory systems necessary to perform the main functions of the robot is determined: vision sensor, reflex sensor. Based on the selected sensor set, the robot can establish the conditions in its immediate vicinity by determining the "safe" distance to the obstacle in several directions through the vision sensor at the current time. Such a comprehensive approach means a systemic solution to the robot's sensing problem based on system-wide optimality criteria determined by the specific purpose of the robot. As a rule, they include such standard indicators as information quality, accuracy, speed, and reliability characteristics.

Robot's motion is carried out by means of commands sent by the control system to the servomotors. These commands allow the robot to turn left and right, move forward and stop. Each rotation and forward movement command changes the state of the robot to a certain discrete quantity, depending on the intensity of the change in the environment and the accuracy of positioning [1-6]. The general structure of an autonomous mobile robot is shown in Fig. 2.

As can be seen from the figure, the robot consists of 7 main parts:

1 – actuating microcontroller in the center,

2 – audio output device on the right,

3 – vision sensor on the left (video, acoustics, etc.),

4 – reflex controllers,

5 – reflex sensors (recognition of the marked line, battery, overcoming obstacles)

6 – motor controllers (2 motors),

7 – controllers of actuating mechanisms (3 actuating mechanisms).

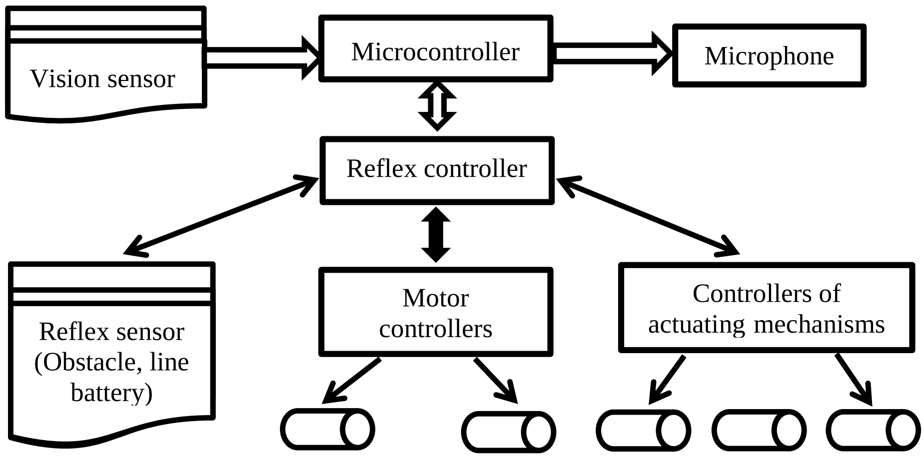

Fig. 2. The general structure of an autonomous mobile robot

The proposed neural control system determines the coordinates of the direction of movement based on the information received from the vision sensor, depending on the intended purpose, and decides further action without colliding with obstacles. If it is impossible to perform such an action at the moment, then the neural control system must stop the robot's motion until the path is clear. To do this, the robot must be equipped with two types of obstacle sensors [3].

- zero-level sensors that directly detect the obstacle in the robot's safety zone;
- ultrasonic sensors that respond to distant obstacles.

Reacting to a zero-level sensor signal means an unconditional shutdown of the system (automatic shutdown of the robot). Based on the signals detected during the search for ultrasonic signals, the robot can estimate the distance to the obstacle and even determine the degree of potential danger. The main requirement for a mobile robot is its safety: the robot must never harm people or objects. Being an autonomous device, the robot has to monitor the energy level of its batteries. If the estimated power of the battery falls below the critical value, the robot must begin the process of searching for a power source. Thus, the main functions of the robot include the following:

1. Movement along a certain route;
2. Rapid response to obstacles in the robot's working area;
3. Rapid response to a decrease in the battery level;
4. Detection of stops on the route and reading the relevant information.

In the model being built, the robot is limited to only three input signals:

1. Overcoming an obstacle;
Measuring the battery level;
3. Determining the accuracy of positioning along the route.

Fig. 3 shows an intelligent neural network model that recognizes the size and position of obstacles during the movement of an autonomous mobile robot, and the lines marked on the map.

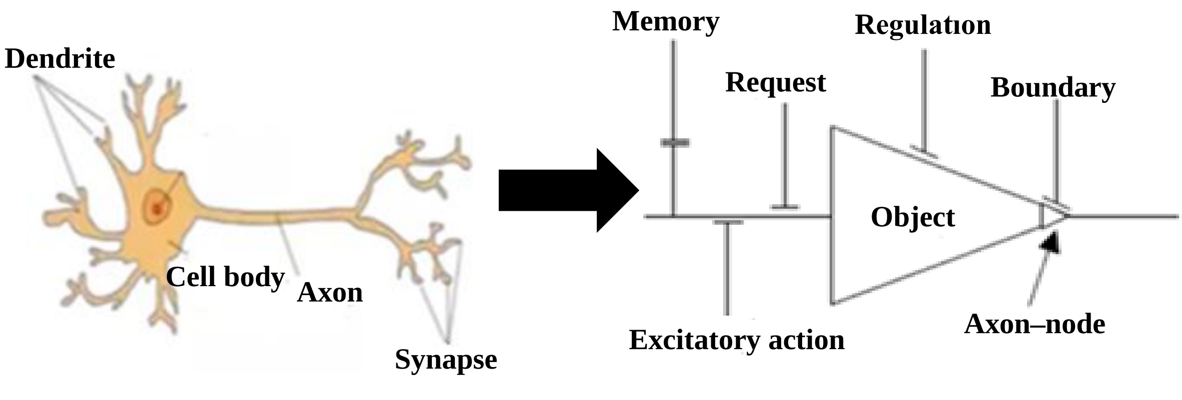

Fig. 3. Intelligent neural network model

As can be seen from the figure, the model of the intelligent neural network includes the following elements: input (memory, excitation, inhibition), boundary, regulation, output (axon–node).

The neural network model can operate in two modes, learning and recognition. Weight coefficients and boundary values are given randomly as neural networks are built. In the state "0", the network solution has no recognition capability. Depending on the nature of the problem, one or another learning procedure is used to provide this capability. Learning takes a lot of machine time for the network to recognize with the required accuracy. During this procedure, the parameters of the neural network (weights, boundaries, and in some algorithms, the structure of the network itself) are modified to ensure the required recognition accuracy. Sometimes this process does not give the desired result. In this case, the selected learning algorithm must be repeated in the state "0" by changing the values of the parameters of the procedure itself [1-6].

4. Modeling of an autonomous mobile robot using an artificial neural network

Fig. 4 shows a functional diagram of a dynamic planning system that predicts the future movement of a robot. As can be seen from the figure, the signals from the sensors (line, obstacle, battery) are converted into pulses, i.e., the control parameters of the generators at the appropriate signal level. The resulting output spiking neurons form a range of existing requirements, which characterizes the robot's short-term action plan. According to this plan, a number of control actions are formed in the robot's actuators.

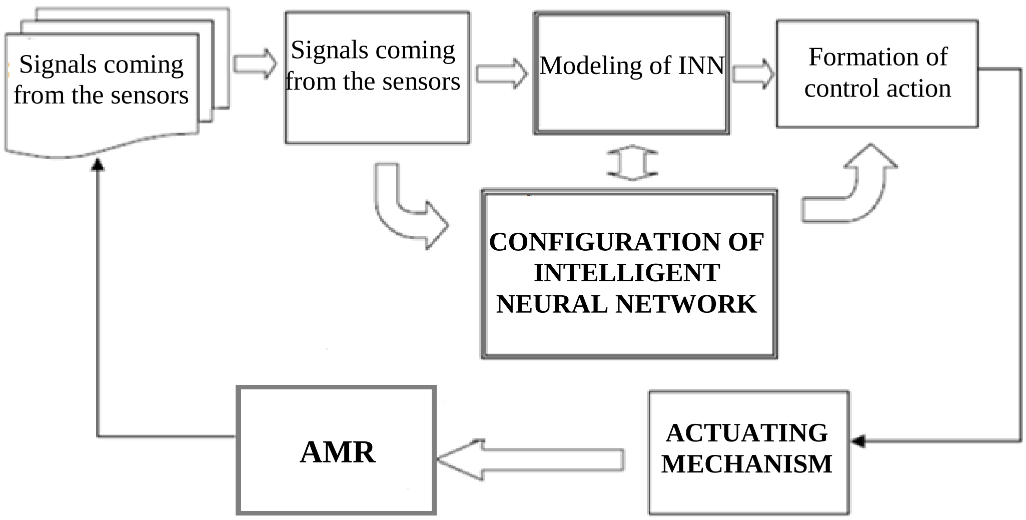

Fig. 4. The functional diagram of AMR using an intelligent neural network

5. Configuring the neural network

To configure the neural network system it is necessary to first form a vector of input signals (speed, obstacle, energy state of the battery, reliability-stability): $X=(x_s, x_m, x_b, x_d)$. The output signals of the neural network are calculated by the known method [1,7]. As we know, in most cases the system functions in an environment of uncertainty, incomplete information. To eliminate uncertainty, additional displacement parameters (right-left shift) are included in the network [7]. The purpose of these parameters is to help the identification of the necessary information.

The main function of the neural network is to provide the necessary functional relationship based on connections between individual neurons. In turn, neurons calculate output signals independently of each other. The size of the output, i.e., the number of variables, is equal to the number of neurons. The nonlinear conversion operator or activation function forms the values of its output signals from the value of the combined input signals. Activation functions can be performed with any of the mathematical functions [1,7]. In practice, linear, transition-step and sigmoidal activation functions are more commonly used, depending on the criteria for error estimation.

With the application of a neural network, various approaches to the formation of the trajectory of an autonomous mobile robot are possible. There are certain requirements for the choice of hardware and software that implement these approaches. These requirements are as follows:

– Hardware computing capabilities;
– Configuration of the working area (size, location of obstacles);
– The speed of determining the coordinates (position);
– Energy consumption requirements (energy expended by the mobile agent to travel over the working area per unit of discrete time);
– Requirements for system reliability.

Based on these criteria, the following approaches can be used to build a planned trajectory system:

– Centralized;
– Decentralized;
– Hybrid (combination).

In a centralized approach, a planned trajectory system, which organizes the coordination of mobile robots, performs all tasks while being controlled by a central server. In this case, all computational operations are controlled from a single center.

In a decentralized approach, each mobile agent has its own planned trajectory system and computational unit. The data are implemented in a distributed manner.

Hybrid (combination) approach is organized depending on the size of the working area of the planned trajectory by combining the two previously discussed approaches.

The modeling of an autonomous mobile robot using an artificial neural network was simulated in the Neural Network application from the Matlab software package. Since the program is a top-level control system, its main function is to make decisions, rather than to process control signals directly to the actuators of the robot. In most cases, the purpose of using parallel computing technologies is to improve the performance of the system software. In general, to evaluate the effectiveness of a parallel computing program, the basic degree of priority (acceleration) is determined by two criteria, namely, the correlation of time spent on solving the problem and the sequential execution of operations to solve the problem.

Thus, it is possible to reduce the solution time several times by parallelizing the program code for an autonomous mobile robot and increasing the number of computers (the number of processors or processor cores). The results of the computer simulation are shown in Fig. 5.

Fig. 5. Computer simulation results

6. Conclusion

With the proposed functional diagram, intelligent control systems for autonomous mobile robots with high flexibility and stability could regulate movement in accordance with overcoming obstacles, measuring battery level and accuracy of positioning on the route. This was also the main feature that distinguished the neural network system from other systems; its learning ability allowed the robot to accurately plan its future movement. This is one of the most interesting features of the neural network system. Autonomous mobile robots can be used to efficiently coordinate planned actions in areas that are hazardous to humans.

References

[1] R.Ə. Əliyev, S.M. Cəfərov, M.C. Babayev və b., İntellektual sistemlərin qurulma prinsipləri və layihələndirilməsi, Bakı, Nərgiz, (2005) 368 p. [In Azerbaijani: R.A. Aliyev, S.M. Jafarov, M.O. Babayev et al., Principles of construction and design of intelligent systems, Baku, Nargiz].

[2] R.Ə. Əliyev, S.M. Cəfərov, M.C. Babayev, E.R. Zeynalov, B.Q. Hüseynov, Robot sistemlərində idarəetmə, Bakı, Nərgiz, (2004) 328 p. [In Azerbaijani: R.A. Aliyev, S.M. Jafarov, M.J. Babayev, E.R. Zeynalov, B.G. Huseynov, Control in robotic systems, Baku, Nargiz].

[3] А.Б. Барский, Нейронные сети: распознавание, управление, принятие решений, Москва, Финансы и статистика, (2004) 176 p. [In Russian: A.B. Barskiy, Neural networks: recognition, control, decision making, Moscow, Finansy i statistika].

[4] Chi K.H.and Lee M.F.R., "Obstacle avoidance in mobile robot using Neural Network," in 2011 International Conference on Consumer Electronics, Communications and Networks (CECNet). (2011) pp. 5082-5085.

[5] I. Dumitrache, M. Dragoicea, Mobile Robots Adaptive Control Using Neural Networks, Proceedings of the 13th Int. Conference on Control Systems and Computer Science CSCS13, Bucuresti, Romania. (2001) pp.176-181.

[6] S.M. Jafarov, E.R. Zeynalov, A.M. Mustafayeva, Synthesis of robust controller – regulators for omnidirectional mobile robot with irregular movement, İnternational Conference on Application of Fuzzy Systems and Soft Computing, İCAFS 2016, 29-30 August 2016, Vienna, Austria, pp.469-476.

[7] E.R. Zeynalov, P.S. Jafarov, A.M. Mustafayeva, S.M. Jafarov, "The methods of analytic synthesis of controllers for dynamic objects described by fuzzy differential equations", Tenth İnternational Conference on Application of Fuzzy Systems and Soft Computing proceedings, Portugal: 29-30 August 2012, pp.85-95.