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Development of intelligent mechatronic motion module of mobile industrial robot

Oleksii S. Shevchuk[1)]
PhD Student, Department of Electromechanical Engineering
ORCID: https://orcid.org/0009-0001-6490-053X; aleksei.shevchuk.ua@stud.op.edu.ua
Vladimir A. Voytenko[1)]
PhD, Associate Professor, Department of Electromechanical Engineering
ORCID: https://orcid.org/0000-0002-2525-6913; voitenko@op.edu.ua
[1)] Odesa Polytechnic National University, 1, Shevchenko Ave. Odesa, 65044, Ukraine

ABSTRACT

Modern industry is inextricably linked with mobile industrial robots, which plays a key role in production processes and warehouse logistics. The intensive introduction of mobile industrial robots has increased the need to improve the energy efficiency of robotic installations due to their significant impact on overall production costs. At the same time, there is a pressing need to reduce the time required to develop and implement mobile industrial robots. This leads to the need to improve and optimize the properties of all components that make up a mobile industrial robot. Currently, electric drives are most widely used in mobile industrial robots. Research shows that the use of modern high-tech solutions in the construction of electric drive control systems can improve the energy efficiency of mobile industrial robots. In turn, the introduction of an intelligent component into mechatronic motion modules allows to reduce the time required for their construction and integration into mobile industrial robots. The purpose of the study is to increase the energy efficiency of an intelligent mechatronic motion module by using a multi-motor electric drive in the movement system of a mobile industrial robot and to develop a stable and energy-efficient intelligent automatic control system based on a neural network, taking into account the nonlinear properties of the control object under conditions of uncertainty.

Keywords: Mobile industrial robot; mechatronic module; automatic control system; multi-motor electric drive; nonlinearity; energy efficiency; uncertainty; neural network

Research relevance. Due to the widespread adoption of mobile industrial robots (MIR) in industry, optimizing their energy consumption is an important area of research as it can lead to significant energy savings and reduce the environmental impact of MIR. Improving the energy efficiency of industrial systems helps improve the environmental condition of our planet and is one of the key means of achieving “zero” emissions, as reflected in the International Energy Agency’s report “Net Zero by 2050” [1]. At the same time, according to the Industry 5.0 concept [2], the requirements for MIR and their modules are increasing, which is due to the large volume of uncertainties, such as non-modeled dynamics, parameter changes and external disturbances. This leads to the need to introduce new high-tech solutions in the construction of MIR and their modules.

The purpose of the study is to build an energy-efficient intelligent mechatronic motion module (IMMM) capable of performing complex tasks independently without the participation of automatic control systems of the upper-level module, while expanding the possibilities of information interaction between the system modules and ensuring the reliability and safety of the module through intelligent diagnostics of faults and protection in abnormal operating modes.

The study examines the construction of an IMMM based on a multi-motor electric drive with its own intelligent automatic control system (ACS). The main attribute of this system is the nonlinearity of its components. In turn, the application environment requires high dynamics of movement when changing the working environment in real time. The system is considered as a multi-mass system, where each engine, including the electric motor, forms a separate mass. As for the state variables, the system is multidimensional with simultaneous control of the electromagnetic torque and the speed of the motor shaft, the time for optimal acceleration and braking depending on the energy consumption. At the same time, the main element of the ACS is a digital computing device, so the system acquires the character of a discrete signal with time quantization, which is typical for pulse systems. The general requirement of the ACS is the automatic change of parameters, structure or control algorithm to ensure energy-efficient movement of the MIR andmaintain system stability under arbitrarily changing external influences and arbitrarily changing internal parameters of the system.

Nowadays, the development of digital technologies leads to an ever-increasing expansion of mechanical systems with components from the electronics and software industries. There is an increase in research aimed at the construction and application of intelligent mechatronic modules. This issue is addressed, for example, in the study [3], which focuses on the issue of interdisciplinary design of modules in mechatronic modular systems.

In the field of MIR, research related to energy efficiency improvement mainly follows two approaches, namely eco-efficient design and eco-efficient programming [4]. These studies show that the introduction of modern high-tech solutions in the construction of MIR and their modules allows for increasing the energy efficiency of their movement systems. So the current research related to the construction of the IMMM combines these two approaches. It combines the energy saving potential of the IMMM by using a multi-motor electric drive in the MIR movement system and development of a sustainable and energy-efficient intelligent ACS based on a neural network. The generalized functional scheme of the IMMM is presented in Fig. 1.

The construction of a modern multi-motor electric drive for moving the MIR based on the IMMM principle provides the following advantages:

– the modular principle of constructing a multi-motor electric drive with an intelligent automatic control system that determines the required number of connected electric motors depending on the current load of the MIR and external disturbing factors allows for a significant increase in the energy efficiency of the MIR;

– increased reliability and safety of the module and the system as a whole, thanks to intelligent diagnostics of faults and protection in abnormal operating modes;

– minimizing the design and production time of the MIR movement system due to the use of a modular approach, which allows focusing only on the selection and integration of the IMMM with the required number of electric motors depending on the required power of the MIR electric drive.

One of the main challenges of the modern theory of automatic control of the electric drive of the MIR is the control of nonlinear electromechanical systems with dynamic changes in load moments under conditions of uncertainty. The uncertainty is caused by the lack of comprehensive information about the influence of external factors on the system and an accurate mathematical model of the control object, which is obtained analytically and may have a significant error compared to the real technical system. Another problem in the development of automatic control systems is the stability of dynamic systems. It depends on the physical properties and parameters of the system and the

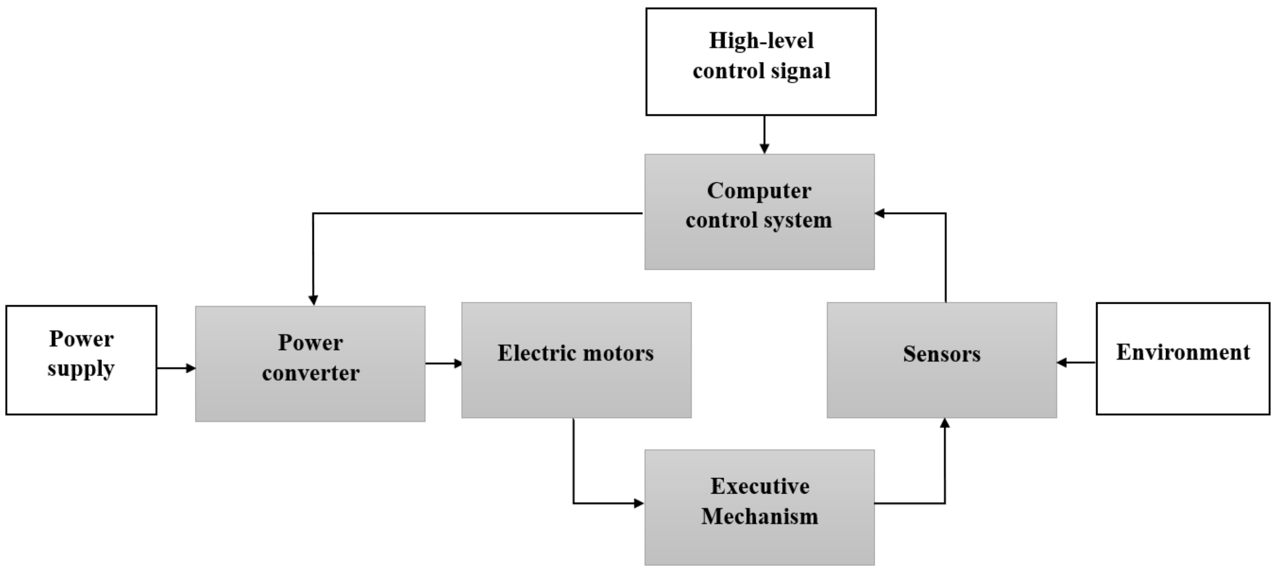

Fig. 1. **Generalized functional scheme of intelligent mechatronic motion module**

magnitude and location of application of the external action. Stability is defined as the ability of a system to maintain limited deviations from equilibrium or its initial state when exposed to external disturbances or changes in system parameters.

To solve these problems, modern research is aimed at using neural networks in automatic control systems of MIR. The life cycle of a neural network (NN) consists of two independent phases, training and network operation. NN are not programmed in the usual sense of the word, they are trained. This is one of the main advantages of NN over traditional algorithms used in ACS. NN-based controllers can be effective in cases where creating an analytical model of the system is extremely difficult.

This can be due to a number of factors, the most common of which are:

– The presence of previously undefined external influences (for example, when operating the MIR in extreme or uncertain environments).
– Significant disturbing internal effects (for example, the action of dry and viscous friction forces in electromechanical devices of the MIR).
– Inconstancy of the parameters and structure of the MIR (for example, replacement of MIR modules during its partial optimization or repair).

One example of constructing a control system for an electric drive with a complex mechanical design and parameter uncertainty is the study [5], in which an adaptive controller with two neural networks was developed to control the speed of a two-mass system. Another study [6] is devoted to ensuring the stability of the system, in which a nonlinear control based on the Lyapunov method is proposed, defined using a neural network that uses Lyapunov theory to calculate the control law for a nonlinear system.

The current study examines the implementation of NN in the construction of the ACS. This can help solve the problem of complex mathematical analysis in constructing sustainability and energy efficiency laws due to the ability of NN to adapt to a real condition and learn from experience. NN can be used to approximate complex mathematical functions that arise in the process of analysis and control of a nonlinear system under uncertainty. Fig. 2 shows a generalized functional scheme of an intelligent ACS of the multi-motor electric drive for MIR movement.

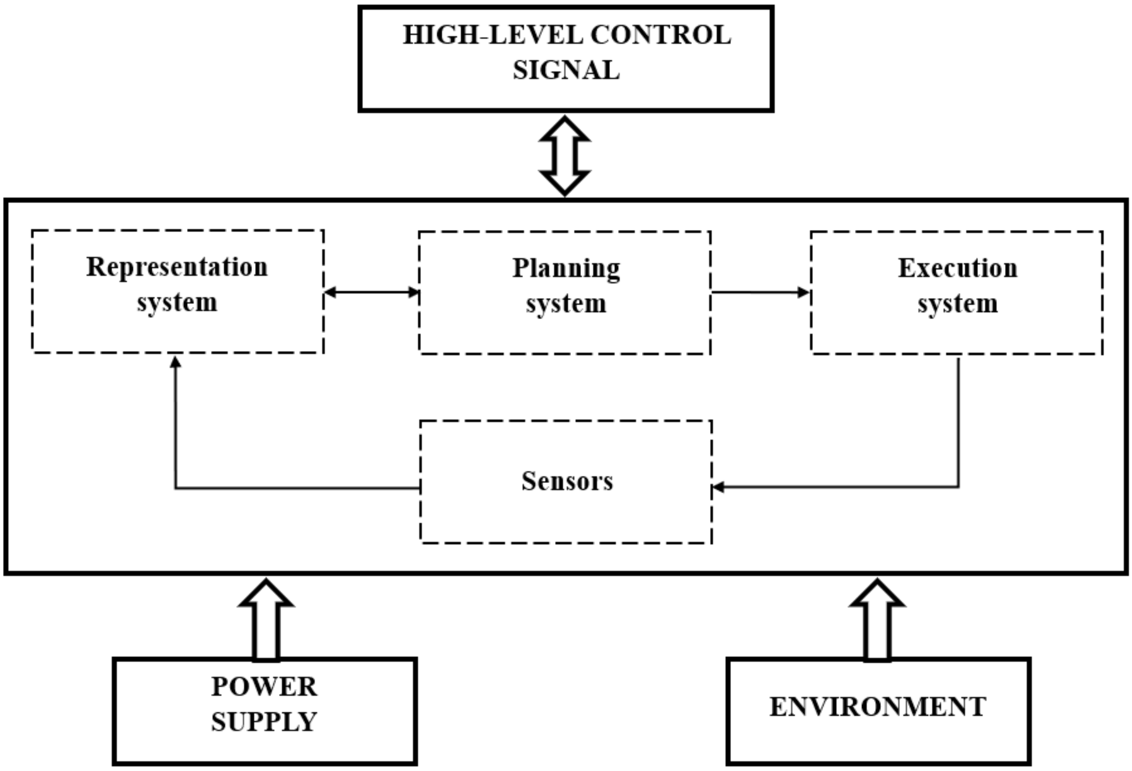

Fig. 2. **Generalized functional scheme of an intelligent automatic control system of the multi-motor electric drive for mobile industrial robots movement**

The development of IMMM for MIR with its own intelligent automatic control system provides the following advantages:

– ability to perform complex tasks independently through the use of intelligent control methods directly at the executive level. This improves the quality of control when the system operates in variable and uncertain environmental conditions;

– development of distributed automated control systems based on personal computers, which significantly simplifies and expands the possibilities of information interaction between system modules, thanks to the use of a single high-level information interface;

– taking into account nonlinear properties of a control object with uncertainty of its parameters and external disturbances.

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Розробка інтелектуального мехатронного модуля руху мобільного промислового робота

Шевчук Олексій Сергійович[1)]

Аспірант кафедри Електромеханічної Інженерії

ORCID: https://orcid.org/0009-0001-6490-053X; aleksei.shevchuk.ua@stud.op.edu.ua

Войтенко Володимир Андрійович[1)]

Канд. техніч. наук, доцент, доцент кафедри Електромеханічної Інженерії

ORCID: https://orcid.org/0000-0002-2525-6913; voitenko@op.edu.ua

[1)] Національний університет «Одеська політехніка», пр. Шевченка, 1. Одеса, 65044, Україна

АНОТАЦІЯ

Сучасна промисловість невід'ємно пов'язана з мобільними промисловими роботами, які відіграють ключову роль у виробничих процесах та складській логістиці. Інтенсивне впровадження мобільних промислових роботів, підвищило необхідність покращення енергетичної ефективності роботизованих установок через їх значний вплив на загальні виробничі витрати. В той же час актуальною є потреба зменшення часу на розробку та впровадження мобільних промислових роботів. Це призводить до необхідності покращення та оптимізації властивостей усіх компонентів, з яких складається мобільний промисловий робот. На данний час найбільше застосування в мобільних промислових роботах мають електроприводи. Дослідження показують, що впровадження сучасних високотехнологічних рішень при побудові систем керування електроприводом дозволяє підвищити енергоефективність мобільних промислових роботів. В свою чергу, впровадження інтелектуальної складової у мехатронні модулі руху, дозволяє зменшити час на їх побудову та інтеграцію в мобільні промислові роботи. Метою дослідження є підвищення енергетичної ефективності інтелектуального мехатронного модуля руху завдяки використанню багатодвигунного електроприводу в системі переміщення мобільного промислового робота та побудові стійкої та енергоефективної інтелектуальної системи автоматичного керування на базі нейромережі з врахуванням нелінійних властивостей об'єкта керування в умовах невизначеності його параметрів і зовнішних збурень.

Keywords: мобільний промисловий робот; мехатронний модуль; система автоматичного керування; багатодвигунний електропривод; нелінійність, енергоефективність; невизначенність; нейронна мережа