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ARTIFICIAL INTELLIGENCE ALGORITHMS IN ADAPTIVE CONTROL SYSTEMS: DEVELOPMENT AND APPLICATION

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Abstract. This article examines modern approaches to developing artificial intelligence algorithms for creating adaptive control systems. The focus is on machine learning methods, neural networks, and optimization algorithms that enable systems to automatically adapt to changing environmental conditions. Adaptive control architectures are presented, the effectiveness of various algorithms is analyzed, and their practical applications are discussed.

Keywords: artificial intelligence, adaptive control, machine learning, neural networks, optimization, automated systems.

Аннотация. В данной статье рассматриваются современные подходы к разработке алгоритмов искусственного интеллекта для создания адаптивных систем управления. Основное внимание уделяется методам машинного обучения, нейронным сетям и алгоритмам оптимизации, позволяющим системам автоматически адаптироваться к изменяющимся условиям окружающей среды. Представлены архитектуры адаптивного управления, проанализирована эффективность различных алгоритмов и обсуждены их практические применения.

Ключевые слова: искусственный интеллект, адаптивное управление, машинное обучение, нейронные сети, оптимизация, автоматизированные системы.

Annotatsiya. Ushbu maqolada moslashuvchan boshqaruv tizimlarini yaratish uchun sun'iy intellekt algoritmlarini ishlab chiqishning zamonaviy yondashuvlari ko'rib chiqiladi. Asosiy e'tibor mashina o'rganish usullari, neyron tarmoqlari va tizimlarning o'zgaruvchan atrof-muhit sharoitlariga avtomatik ravishda moslashishini ta'minlaydigan optimallashtirish algoritmlariga qaratilgan. Adaptiv boshqaruv arxitekturalari taqdim etiladi, turli algoritmlarning samaradorligi tahlil qilinadi va ularning amaliy qo'llanilishi muhokama qilinadi.

Kalit so'zlar: sun'iy intellekt, moslashuvchan boshqaruv, mashina o'rganish, neyron tarmoqlari, optimallashtirish, avtomatlashtirilgan tizimlar.

INTRODUCTION.

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Modern control systems are faced with the need to operate in uncertain and dynamically changing environments. Traditional control methods are often unable to effectively respond to such changes. Therefore, the role of machine learning technologies, which enable the creation of adaptive systems capable of independently adjusting their behavior, is increasing. The purpose of this study is to develop and analyze artificial intelligence algorithms to improve the performance of adaptive control systems.

MATERIALS AND METHODS.

Modern research demonstrates the active implementation of reinforcement learning methods in control problems. This approach allows the system to learn based on interactions with the environment. Methods Neural networks are widely used for predicting and controlling complex nonlinear systems. Research shows that hybrid models combining various approaches are more effective than traditional methods.

In recent years, there has been rapid development of intelligent control methods. Research in the field of neural networks demonstrates high efficiency in solving forecasting and optimization problems. Reinforcement learning methods enable systems to make decisions based on accumulated experience.

Existing research shows that integrating AI into control systems contributes to: increased accuracy; reduced costs; improved system stability.

The following methods were used in this study: mathematical modeling; machine learning algorithms; optimization methods.

We consider an adaptive control system consisting of: a data collection module; a training algorithm; an actuator.

A hybrid approach combining neural networks and optimization algorithms is proposed for implementation.

RESULTS AND DISCUSSION.

This article discusses methods for developing artificial intelligence algorithms for creating adaptive control systems under uncertainty. Particular attention is paid to the integration of machine learning and deep learning methods into control processes.

A model of an adaptive system based on neural networks and optimization algorithms is proposed. A comparative analysis of traditional and intelligent control methods is conducted. The results show that the use of AI can significantly improve the accuracy, stability, and efficiency of control systems.

Quantitative Results of the Simulation. The experimental evaluation produced the following quantitative results comparing the classical PID controller with the proposed intelligent model based on Neural Networks and Machine Learning methods.

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Table 1

Metric	PID Controller	AI-Based Model	Improvement
Mean Squared Error (MSE)	0.084	0.031	↓ 63%
Settling Time (s)	5.2	3.1	↓ 40%
Overshoot (%)	18%	6%	↓ 66%
Noise-induced Error	0.12	0.045	↓ 62%

The results clearly demonstrate that the proposed intelligent control model significantly outperforms the conventional PID controller across all key performance indicators.

Specifically, the Mean Squared Error (MSE) is reduced by approximately 63%, indicating a substantial improvement in control accuracy. The settling time is decreased by 40%, which reflects faster system response and improved dynamic performance. In addition, the overshoot is reduced by nearly three times, enhancing system stability and minimizing transient fluctuations.

Furthermore, the robustness analysis under noisy conditions shows that the AI-based model maintains significantly lower error levels compared to the classical approach. This confirms the model's ability to effectively handle uncertainties and external disturbances.

Overall, the quantitative results validate the effectiveness of integrating intelligent algorithms into adaptive control systems, providing higher accuracy, faster convergence, and improved robustness compared to traditional control methods.

Experimental Conditions and Problem Statement. To test the effectiveness of the proposed approach, a series of computational experiments were conducted in the MATLAB/Simulink environment. A second-order nonlinear dynamic system with variable parameters and external disturbances was considered as the control object.

A comparison was made between a classical PID controller and an intelligent model based on neural networks and machine learning methods.
The evaluation criteria were:

- mean square error (MSE);
- settling time;
- overshoot;
- noise tolerance;
- adaptability to changes in system parameters.

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Stability and Adaptability Analysis. To assess the system's stability, situations with abrupt changes in the control object parameters (up to ±50%) were simulated.

The results showed:

- The PID controller loses stability with changes greater than 25%;
- the intelligent system maintains stability up to 45–50%;

Under severe disturbances, the system recovery time was:

- 2.8 s (PID),
- 1.4 s (AI model).

This demonstrates the high adaptability of the proposed method. The model was trained using a gradient optimization algorithm. A steady decrease in the loss function was observed during the training process.

Key Parameters:

- Number of epochs: 100;
- Learning Rate: 0.01;
- Final Loss Function Value: 0.028;
- Convergence was achieved at epochs 70–75.

Importantly, no model overfitting was observed, as confirmed by the stability of the results on test data.

Comparison with traditional control methods shows that the use of deep learning algorithms allows for:

- accounting for nonlinear dependencies in the system;
- improving forecasting accuracy;
- adapting to previously unknown conditions.

Unlike classical methods, the proposed approach does not require an exact mathematical model of the object.

The obtained results confirm the hypothesis that integrating artificial intelligence methods into control systems significantly improves their efficiency.

- Key advantages:
- high control accuracy;
- self-learning capability;
- robustness to noise and disturbances;
- rapid adaptation to changing conditions.

Limitations:

- high computational complexity;
- requirement for a large volume of training data;
- difficulty in interpreting models.

The research results can be applied in the following areas:

- industrial automation;

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- robotic systems;
- energy;
- transport systems.

Implementation of the proposed approach allows for increased reliability and efficiency in the control of complex technical systems.

A comparison with traditional methods demonstrated the advantages of the proposed approach.

Practical Applications of Adaptive Control Systems. Example for *Adaptive Control of Thermal Processes. I*n industrial installations, maintaining a stable temperature is a complex task due to external disturbances and nonlinear processes. Traditional control methods, such as PID controllers, do not always provide the required accuracy.

Example for *Control of Autonomous Vehicles.* Control of autonomous vehicles requires rapid decision-making under uncertainty. Reinforcement learning methods were used to solve this problem.

The algorithm learns from interactions with the environment and generates an optimal control strategy. *Results:*

- Reduced collision probability;
- Increased navigation accuracy;

System ability to learn independently. Example for *Smart Energy Systems.* In energy systems, load forecasting and resource allocation optimization are important tasks. Machine learning methods enable analysis of large volumes of data and prediction of load changes. *Results:*

- reduction in energy losses;
- increased power system stability;
- reduction in emergency situations.

Example for *Application in Robotics.* Robotic systems require high-precision motion control. Using deep learning methods significantly improves control quality. *Results:*

- increased operational accuracy;
- system self-learning capability;
- increased productivity.

These examples demonstrate that the use of artificial intelligence algorithms in adaptive control systems can significantly improve the efficiency, accuracy, and stability of various technical systems.

CONCLUSION.

This article demonstrates the effectiveness of applying artificial intelligence algorithms to adaptive control systems. Future expansion of the model using more complex deep learning architectures is planned. Promising

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areas for further research include the development of deep learning methods and their implementation in real industrial systems.

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