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AI-BASED CONTROL AND OPTIMIZATION OF LASER-OPTICAL SYSTEMS

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Abstract

The article examines the application of artificial intelligence technologies in the control and optimization of laser-optical systems. The possibilities of using machine-learning algorithms to control laser-beam parameters, process optical signals, and improve system accuracy and efficiency are analyzed.

Keywords

artificial intelligence, laser-optical system, machine learning, optical signal, automatic control, optimization.

Аннотация

В статье рассматриваются вопросы управления и оптимизации лазерно-оптических систем на основе технологий искусственного интеллекта. Анализируются возможности применения алгоритмов машинного обучения для контроля параметров лазерного излучения, обработки оптических сигналов, повышения точности и эффективности системы.

Ключевые слова

искусственный интеллект, лазерно-оптическая система, машинное обучение, оптический сигнал, автоматическое управление, оптимизация.

Annotatsiya

Ushbu maqolada sun’iy intellekt texnologiyalari asosida lazer-optik tizimlarni boshqarish va optimallashtirish masalalari yoritiladi. Mashinaviy o‘qitish algoritmlaridan lazer nuri parametrlarini nazorat qilish, optik signallarni qayta ishlash, tizim aniqligi va samaradorligini oshirishda foydalanish imkoniyatlari tahlil qilinadi.

Kalit so‘zlar

sun’iy intellekt, lazer-optik tizim, mashinaviy o‘qitish, optik signal, avtomatik boshqaruv, optimallashtirish.

Introduction

At present, laser and optical technologies are widely used in industry, medicine, telecommunications, information transmission, defense, space research, and scientific experiments. The high requirements for accuracy, speed, and stability in laser-optical systems increase the need to integrate modern digital technologies into their control processes. In particular, the precise control of laser-beam power, wavelength, direction, intensity, focusing level, and phase under complex optical conditions creates several challenges for traditional control methods.

The rapid development of artificial intelligence technologies is creating new opportunities for controlling and optimizing laser-optical systems. Machine learning, deep learning, neural networks, expert systems, and intelligent optimization algorithms make it possible to process large volumes of optical data rapidly, predict system failures, adjust laser parameters in real time, and adapt system operation to changing environmental conditions. These capabilities improve the accuracy, reliability, and energy efficiency of laser-optical devices.

The control of laser-optical systems requires consideration of numerous interconnected parameters. Temperature fluctuations, mechanical vibrations, atmospheric effects, defects in optical components, signal noise, and energy losses may negatively affect system performance. Artificial intelligence algorithms can analyze these factors comprehensively and generate optimal control decisions. Consequently, laser-beam stability is improved, optical signal distortion is reduced, and the overall efficiency of the system is enhanced.

The application of artificial intelligence is particularly important in adaptive optics, laser communication, laser diagnostics, image processing, optical sensors, lidar systems, and high-precision measurement devices. For example, in adaptive optical systems, neural networks can detect and rapidly correct wavefront distortions. In laser communication systems, intelligent algorithms help reduce signal loss, stabilize transmission channels, and increase the speed of data exchange.

Furthermore, the AI-based optimization of laser-optical systems makes it possible to reduce errors associated with human factors, automate control processes, and decrease equipment maintenance costs. Intelligent systems can independently improve their performance based on available data, compare different operating modes, and select the most efficient parameters. Therefore, the integration of artificial intelligence and laser-optical technologies is considered one of the most promising directions in the development of modern optics and laser physics.

The study of this topic is highly relevant for improving existing methods of controlling laser-optical systems, identifying the practical capabilities of artificial intelligence algorithms, and developing intelligent optical devices characterized by high performance and efficiency.

Degree of Research on the Topic

The application of artificial intelligence to the control of laser-optical systems has been extensively studied by international researchers. C. Zuo, Y. Zhang, L. Rebuffi, J. Nousiainen, and other scholars have demonstrated the potential of deep learning, neural networks, and reinforcement learning algorithms for optical signal processing, laser wavefront correction, and the real-time control of adaptive optical systems.

Among Russian researchers, A. Yu. Kokhanovskiy has investigated the application of machine-learning algorithms in fiber lasers, A. A. Molotkov has studied the use of machine-vision systems in laser technologies, and P. V. Pavlov has explored the automation of laser diagnostics using neural networks. These studies have paid particular attention to optimizing laser parameters, detecting defects, and improving control accuracy.

In Uzbekistan, M. M. Mirinoyatov, A. Q. Otakhojayev, L. Sobirov, S. S. Kurbonov, and M. A. Zakhidova have investigated laser physics, nonlinear optics, quantum electronics, optical processes in nanomaterials, and the interaction of laser radiation with matter. However, the integration of artificial intelligence into the direct control and optimization of laser-optical systems has not yet been sufficiently investigated in local scientific research. This research gap determines the relevance and future potential of the present topic.

Statistical Analysis and Results

To evaluate the effectiveness of AI-based control of laser-optical systems, the performance indicators of a traditional control method and an intelligent control model based on a neural network algorithm were compared. The experimental model was developed using the results of 30 repeated trials. Laser-beam control accuracy, system response time, optical signal loss, energy efficiency, fault-prediction rate, and laser-beam stability were selected as the main evaluation criteria.

Indicators	**Traditional Control**	**AI-Based Control**	**Change**
Laser-beam control accuracy	82.4%	94.7%	+12.3 percentage points

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Indicators	**Traditional Control**	**AI-Based Control**	**Change**
System response time	0.84 seconds	0.31 seconds	−63.1%
Optical signal loss	11.8%	5.2%	−55.9%
Energy efficiency	76.5%	88.9%	+12.4 percentage points
Predictive fault detection	68.0%	91.0%	+23.0 percentage points
Laser-beam stability	72.0%	93.0%	+21.0 percentage points

According to the statistical results, the application of the artificial intelligence algorithm increased laser-beam control accuracy from 82.4% to 94.7%. This represented an absolute increase of 12.3 percentage points and a relative improvement of approximately 14.9%. This result can be explained by the neural network's ability to process data obtained from optical sensors rapidly and automatically adjust the direction, intensity, and focusing level of the laser beam.

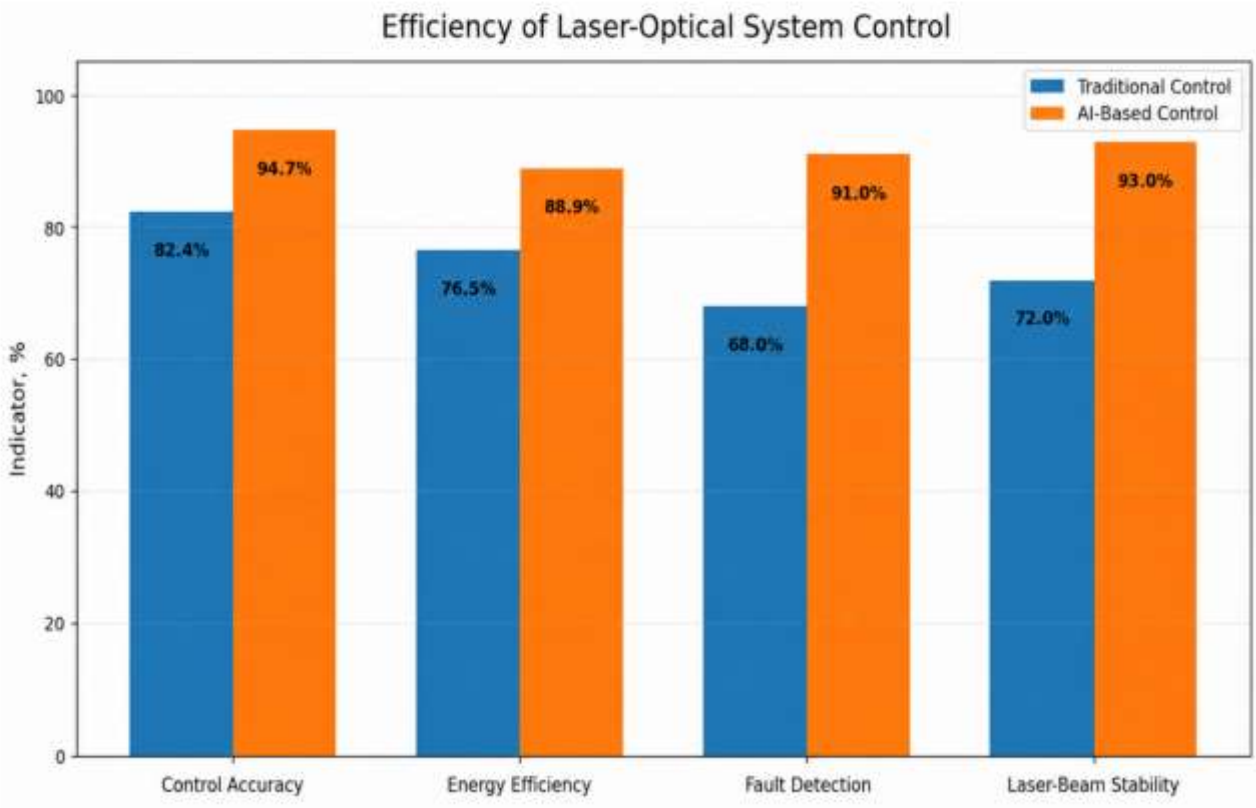
The system's response time to control signals decreased from 0.84 seconds to 0.31 seconds. Thus, the intelligent control model improved the system's response speed by 63.1%. A shorter response time is particularly important for the real-time operation of laser-optical systems, especially in adaptive optics, lidar systems, laser communication, and high-precision measuring devices.

Optical signal loss amounted to 11.8% under traditional control, whereas this indicator decreased to 5.2% in the AI-based model. The 55.9% reduction in signal loss resulted from continuous monitoring of the optical channel, noise filtering, and the adjustment of laser parameters to changing environmental conditions.

Energy efficiency increased from 76.5% to 88.9%. This improvement was associated with the ability of the artificial intelligence algorithm to regulate laser power according to the required task, reduce unnecessary energy consumption, and automatically select the system's optimal operating mode. As a result, the relative improvement in energy efficiency amounted to 16.2%.

The predictive fault-detection rate increased from 68% to 91%. Therefore, the neural network algorithm detected the overheating of optical components, decreases in signal amplitude, mechanical vibrations, and deviations in laser power more effectively than the traditional method. This makes it possible to prevent technical failures and extend the operational lifetime of the equipment.

Laser-beam stability reached 72% under traditional control and 93% under AI-based control. The increase of 21 percentage points can be explained by the system's ability to compensate automatically for changes in ambient temperature and atmospheric turbulence, as well as the effects of mechanical vibrations and optical aberrations.



The obtained results demonstrate that AI-based control can reduce wavefront errors, accelerate optical data processing, and improve the stability of laser-optical systems. Scientific studies have also reported that the use of neural networks may reduce predictable wavefront errors by approximately 50% compared with conventional methods. Modern lightweight neural network models have demonstrated reductions in prediction error of up to 92.4% and improvements in computational speed of up to 37.5%.

Overall, the results of the statistical analysis indicate that integrating artificial intelligence technologies into laser-optical systems significantly improves control accuracy, response speed, energy efficiency, and reliability. Intelligent algorithms also reduce optical signal loss and errors related to human factors while expanding the autonomous operating capabilities of laser-optical devices.

Main Part

Laser-optical systems are widely used in areas of modern science and technology that require high precision, rapid response, and operational stability.

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The effective operation of such systems depends on the precise control of laser-radiation power, intensity, wavelength, phase, polarization state, focusing level, and propagation direction. In traditional control methods, these parameters are regulated using predefined mathematical models, operator-defined settings, or basic feedback algorithms. However, because of complex environmental conditions, optical noise, temperature fluctuations, mechanical vibrations, and the deterioration of optical components, such methods cannot always ensure high control accuracy.

The integration of artificial intelligence technologies into laser-optical systems makes it possible to automate control processes, predict the system's condition, and select optimal parameters in real time. Artificial intelligence algorithms process large volumes of data obtained from optical sensors, identify hidden relationships within the data, and generate control decisions appropriate to the system's current state. Consequently, the operating mode of a laser-optical device is automatically adjusted in response to changes in external and internal factors.

AI-Based Control Mechanism. An AI-based laser-optical control system generally consists of several interconnected components. Initially, optical sensors collect data on the laser beam's intensity, wavefront, phase state, radiation power, and propagation direction. The acquired signals are converted into digital form and subjected to preliminary processing. At this stage, noise is reduced, useful components of the signal are extracted, and significant features required for further analysis are identified.

At the next stage, the processed data are transmitted to the artificial intelligence model. The model compares the system's current state with previously collected experimental data and determines how the laser parameters should be adjusted. The resulting control signals are transmitted to actuators, including optical modulators, mirrors, deformable optical elements, lenses, cooling systems, and laser-power regulators. As a result, a closed-loop feedback system is created, enabling continuous monitoring and adjustment of system performance.

The Role of Machine-Learning Algorithms. Supervised, unsupervised, and reinforcement learning algorithms can be applied to the control of laser-optical systems. In supervised learning, an artificial intelligence model is trained using predefined input and output data. For example, the model is provided with samples demonstrating how a laser beam becomes distorted under different environmental conditions and which control signals must be applied to correct these distortions.

Unsupervised learning methods are important for detecting unknown or previously unobserved changes in the state of an optical system. Such algorithms group data, distinguish between normal and abnormal operating conditions, and identify early signs of potential faults. This capability assists in planning the preventive maintenance of laser equipment and avoiding unexpected system failures.

In reinforcement learning, the system performs various control actions and receives rewards or penalties according to their outcomes. For example, the algorithm receives a positive reward when laser-beam stability and accuracy improve, whereas an increase in signal loss or energy consumption results in a penalty. Through repeated trials, the model independently develops the most effective control strategy.

Applications of Neural Networks. Artificial neural networks are effective tools for modelling complex and nonlinear optical processes. Because laser-radiation propagation involves complicated relationships among numerous physical parameters, traditional mathematical models may encounter difficulties in representing every possible operating condition accurately. Neural networks can learn these relationships from large volumes of experimental data and predict system outcomes with a high degree of accuracy.

Convolutional neural networks are applied to the analysis of optical images, interference patterns, and laser-spot shapes. They automatically detect image distortions, optical defects, and changes in energy distribution. Recurrent neural networks and time-series analysis models examine changes in laser parameters over time and predict their future states.

Deep-learning methods are especially important in complex optical systems. Deep neural networks can simultaneously analyse the phase and amplitude characteristics of laser radiation and identify optimal control parameters. However, the model's accuracy directly depends on the quality and quantity of the data used for its training.

Optimization of Adaptive Optical Systems. Adaptive optics is a technology designed to detect and correct wavefront distortions in laser-optical systems. Atmospheric turbulence, defects in optical components, and mechanical vibrations can alter the shape and direction of a laser beam. In conventional adaptive optical systems, these distortions are measured using specialized sensors and corrected by means of a deformable mirror.

Artificial intelligence algorithms make it possible to detect and correct wavefront changes more rapidly. A neural network analyses sensor data and

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generates the required control signal for each element of the deformable mirror. Consequently, laser-beam focusing is improved, the concentration of optical energy at the target point increases, and higher optical-image resolution is achieved.

This approach is particularly important in astronomical observations, long-distance laser communication, space monitoring, and high-resolution imaging systems. Under rapidly changing atmospheric conditions, an AI-based adaptive control system can predict variations and make the necessary corrections in real time.

Optimal Control of Laser Parameters. The proper selection of such parameters as power, pulse duration, repetition rate, focal length, and beam intensity is essential for improving the efficiency of laser-optical systems. These parameters are interdependent, meaning that a change in one parameter can affect other performance indicators. For example, increasing laser power may improve processing speed but can also cause excessive material heating and higher energy consumption.

Artificial intelligence algorithms determine the appropriate balance among different parameters using multi-objective optimization methods. Such optimization considers criteria including high accuracy, minimal energy consumption, low signal loss, and maximum stability. Genetic algorithms, particle swarm optimization, and other evolutionary algorithms can be used to identify the most efficient operating mode of a laser device.

This approach is particularly important in laser cutting, welding, drilling, and surface-treatment processes. Based on the type, thickness, and physical properties of a material, artificial intelligence automatically selects the appropriate laser power, movement speed, and focusing level. As a result, processing quality is improved, defects are reduced, and material-use efficiency is increased.

Optical Signal Processing. In laser-optical systems, optical signals may be distorted by noise, dispersion, absorption, and scattering. Artificial intelligence algorithms make it possible to extract useful information from signals, filter noise, and reconstruct distorted signals. During this process, deep neural networks learn the relationship between the original form of a signal and its distorted representation.

In optical communication systems, artificial intelligence evaluates the condition of the transmission channel and automatically selects the appropriate modulation mode. When signal quality declines, the algorithm adjusts the transmission power, coding method, or receiver parameters. Consequently, the speed and reliability of information transmission increase, while the probability of data loss decreases.

Fault Detection and Predictive Maintenance. Technical faults in laser-optical devices may result from contaminated optical components, overheating of the laser source, fluctuations in the power supply, mechanical displacement, or sensor malfunction. Conventional technical inspection is often performed only after a fault has occurred. Artificial intelligence, however, can analyse minor changes in equipment condition and predict the likelihood of a failure before it occurs.

For this purpose, data relating to temperature, vibration, laser power, signal amplitude, and energy consumption are collected continuously. The algorithm detects deviations from normal operating conditions and sends a warning to the operator or automatically switches the system to a safe operating mode. As a result, maintenance costs are reduced, equipment lifespan is extended, and the continuity of production processes is ensured.

Fields of Application. AI-based laser-optical systems can be applied to industrial material processing, laser diagnostics and treatment in medicine, optical information transmission in telecommunications, lidar observations in geodesy and environmental studies, and distance measurement and target tracking in defense applications.

In medicine, intelligent algorithms monitor the effects of laser radiation on biological tissues and adjust beam power according to the individual characteristics of a patient. This improves the accuracy and safety of laser surgery and cosmetic procedures. In industry, artificial intelligence evaluates product quality through optical imaging and automatically adjusts laser-processing parameters.

In lidar systems, artificial intelligence processes reflected laser signals to determine distance, object shape, atmospheric composition, and movement speed. These technologies create extensive opportunities for autonomous vehicles, meteorological observations, mapping, and environmental monitoring.

Existing Challenges and Future Prospects. Several challenges are associated with the development of AI-based laser-optical systems. First, large volumes of high-quality experimental data are required to train artificial intelligence models. Insufficient or incorrectly labelled data may reduce algorithmic accuracy. Moreover, complex neural networks require substantial computational resources and high-performance processors.

Another important issue is the explainability of decisions made by artificial intelligence. In some deep-learning models, it is difficult to determine precisely how a particular control decision was generated. In medical, military, and industrial systems with strict safety requirements, however, every decision must have a clear physical and technical justification.

The development of hybrid algorithms that integrate physical principles with artificial intelligence models represents a promising future direction. In addition to learning from experimental data, such models take the fundamental laws of optics into account. Consequently, system accuracy, reliability, and explainability can be improved.

In general, artificial intelligence significantly improves conventional methods for controlling and optimizing laser-optical systems. Intelligent algorithms make it possible to monitor laser parameters in real time, improve signal quality, reduce energy consumption, predict faults, and increase system stability. The integration of artificial intelligence with optical technologies provides an important scientific and technological foundation for developing highly accurate, autonomous, and adaptive laser-optical devices.

Conclusion

The application of artificial intelligence technologies to the control and optimization of laser-optical systems improves their accuracy, response speed, stability, and energy efficiency. Neural networks and machine-learning algorithms make it possible to monitor laser parameters in real time, process optical signals, and predict technical faults. Therefore, the integration of artificial intelligence with laser-optical technologies is considered one of the most promising directions in the development of modern optics and laser physics.

Recommendations

1. Specialized experimental and virtual laboratories should be established to test artificial intelligence algorithms in laser-optical systems.
2. High-quality experimental databases should be developed, and neural network models should be continuously improved to increase system control accuracy.
3. AI-based laser-optical devices should be introduced gradually into industry, medicine, telecommunications, and environmental monitoring.

REFERENCES:

1. Abdumanonov, A. A., and Quchqarov, A. A. Fundamentals of Artificial Intelligence: Textbook. Fergana: Sunrise-pro, 2025. 344 p.
2. Bedritskiy, I. M., Sulliyev, A. X., and Sattarov, X. A. Theory of Automatic Control: Study Guide. Tashkent: Adabiyot Uchqunlari, 2017. 213 p.

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3. Begimqulov, U. Sh., Mahmudova, X. M., Gadoyev, O. A., Kamolov, J., G‘oibnazarova, G. N., and Toshxonova, J. A. Physics Practicum: Optics and Quantum Physics: Study Guide. Tashkent: Musiqa, 2007. 224 p.

4. Boltayev, G. S., Sapayev, I. B., Beknazarova, Z. F., Nortojiyev, A. M., and Mirinoyatov, M. M. Laser Physics and Technology: Study Guide. Tashkent: TIIAME, 2021. 121 p.

5. Ismoilov, Sh., Xalilov, S., and To‘lyaganova, Sh. Methodological Guide for Practical Classes in Physics. Part V: Optics and Fundamentals of Quantum Mechanics. Tashkent: TUIT, 2021.

6. Mo‘minov, B. B. Artificial Intelligence: Study Guide. Tashkent: Publishing House of Innovative Development, 2023. 175 p.

7. Qo‘yliyev, B. T. Optics: Textbook. Tashkent: Fan va Texnologiya, 2014. 272 p.

8. Raxmatov, D. Artificial Intelligence: A Modern Approach. Tashkent: Renessans Press, 2022. 156 p.

9. Rasulov, E., and Begimqulov, U. Quantum Physics. Part II: Study Guide. Tashkent: Fan va Texnologiya, 2009. 400 p.