ТЕХНОЛОГІЇ ЯК ФАКТОР ЕКОНОМІЧНОГО ЗРОСТАННЯ

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THE PROBLEM OF ENERGY EFFICIENCY OF SYSTEMS BASED ON ARTIFICIAL INTELLIGENCE OF THE INTERNET OF THINGS (AIOT)

ПРОБЛЕМАТИКА ЕНЕРГОЕФЕКТИВНОСТІ СИСТЕМ НА ОСНОВІ ШТУЧНОГО ІНТЕЛЕКТУ ІНТЕРНЕТУ РЕЧЕЙ (AIOT)

The article reveals the economic, energy, and environmental aspects of the integration of the Internet of Things (IoT) and artificial intelligence (AI) in the technology of the artificial intelligence of the Internet of Things (AIoT). The scientific problem is defined as the commercial attractiveness of artificial intelligence in the Internet of Things and energy savings. The focus is on compliance with the provisions of sustainable development, particularly the seventh goal, «Affordable and Clean Energy,» and the ecological footprint. Additional energy costs and increased carbon emissions can become significant with more complex AIoT neural architectures. The feasibility of using a metric based on the energy cost of the AIoT life cycle (eCAL) is emphasized. Scaling AIoT is possible when building a Smart City or similar locally concentrated structures. The emphasis is on allocating conventionally fixed and conventionally variable costs for AIoT. It was determined that integrating artificial intelligence functionality into the IoT infrastructure provides the opportunity to store big data for processing using artificial intelligence elements capable of conducting predictive analysis to make informed management decisions. AIoT energy efficiency can be ensured on the basis of the following: selection of machine learning methods, hardware improvement, software optimization, network planning, effective model design, and energy consumption testing with subsequent conclusions for comprehensive improvement. The scientific novelty is a methodological approach to a thorough study of the processes of AIoT implementation in technological development based on energy efficiency, considering the cost of energy in the AIoT life cycle (eCAL), and the ecological footprint of AIoT systems. The direction of further scientific research is determined, which consists of the need for economic and mathematical analysis of production systems formed based on artificial intelligence of the Internet of Things.

Ключові слова: *energy efficiency, artificial intelligence of the internet of things, sustainable development.*

У статті розкрито економічні, енергетичні та екологічні аспекти інтеграції інтернету речей (IoT) та штучного інтелекту (ШІ) у технологію штучного інтелекту інтернету речей (AIoT). Науковою проблематикою визначено комерційну привабливість штучного інтелекту в інтернеті речей та енергозбереження. Основну увагу приділено дотриманню положень сталого розвитку, зокрема досягнення сьомої цілі «Доступна та чиста енергія» та проблемі екологічного сліду. Наголошено на те, що додаткові витрати на енергію та збільшення викидів вуглецю можуть стати значними із використанням складніших нейронних архітектур AIoT. Підкреслено доцільність використання метрики на основі вартості енергії протягом життєвого циклу AIoT (eCAL). Масштабування AIoT можливо при будівництві Smart City або подібних локально зосереджених структур. Акцент зроблено на розподілі умовно-постійних і умовно-змінних витрат для AIoT. Визначено, що інтеграція функціональності штучного інтелекту в інфраструктуру IoT надає можливість зберігати великі дані для обробки за допомогою елементів штучного інтелекту, здатних проводити прогнозний аналіз для прийняття обґрунтованих управлінських рішень. Енергоефективність AIoT може бути забезпечена на основі такого: вибір методів машинного навчання; вдосконалення апаратного забезпечення; оптимізація програмного забезпечення; мережеве планування; ефективне проектування моделі та тестування енергоспоживання з подальшими висновками для комплексного вдосконалення. Наукова новизна полягає в методичному підході до ґрунтовного дослідження процесів впровадження AIoT у технологічний розвиток на основі енергоефективності з урахуванням вартості енергії в життєвому циклі AIoT (eCAL) та екологічного сліду AIoT систем. Визначено напрям подальших наукових досліджень, який полягає в необхідності економіко-математичного аналізу виробничих систем, сформованих на основі штучного інтелекту інтернету речей.

Ключові слова: *: енергоефективність, штучний інтелект Інтернету речей, сталий розвиток.*

Problem statement. The development of a knowledge economy in the era of Industry 4.0 and Society 5.0 is based on realizing the creative potential of Man and innovation. The Internet of Things (IoT) is gradually becoming a tool for the intensive development of production and commercial structures. Recently, artificial intelligence (AI) tools have entered the global market. When both technologies (AI + IoT) are combined, it is called artificial intelligence of the Internet of Things (AIoT). Such a combination requires additional scientific research from an economic point of view.

The modern Internet of Things is the improvement of radio-electronic devices and the convergence of sensor technologies and data processing technologies. Consumers are increasingly demanding electronic services, which poses new challenges for IoT. Such challenges include the development of intelligent architectures and services in the Internet of Things. This creates the prerequisites for implementing the principles of artificial intelligence in the Internet of Things. A separate component is the study of the economic aspects of the production and use of smart sensors, edge computing, and software-defined networks.

The scientific problem is determining the commercial attractiveness of artificial intelligence in the Internet of Things, on the one hand, and energy saving, on the other. This is due to the need to comply with sustainable development provisions, particularly the seventh goal, "Affordable and Clean Energy" [1] These two sides are somewhat contradictory because artificial intelligence requires significant energy consumption. However, the development of microelectronics provides opportunities to reduce the energy consumption of radio-electronic devices. AIoT software can significantly impact energy efficiency. It is on it that efforts can be focused on increasing the efficiency of AIoT use in industry and households. This can improve the quality and safety of life, which meets the principles of sustainable development.

Analysis of recent research and publications. In connection with the need to achieve sustainable development goals, new technological challenges create particular problems for the seventh sustainable development goal – energy. According to the authors of the scientific paper [2], AIoT has become an essential factor in ensuring sustainability and achieving these goals. Scientists, using bibliometric analysis and scientific cartographic analysis, investigated and provided an overview of the role of artificial intelligence (AI), the Internet of Things (IoT), and artificial intelligence of things (AIoT) in the implementation of the principles of sustainable development.

The study of literary [3] sources emphasizes that devices with artificial intelligence of things are assistive technologies. The author agrees with this definition because these devices, as a rule, are integrated into more complex systems. Artificial intelligence models and machine learning have already provided significant opportunities for the development of technology and technology. This work considers the possibility of implementing AIoT devices to a greater extent with computer vision. This is relevant for ensuring a higher quality of life for people with visual impairments.

Ukrainian scientific works also consider the issues of the Internet of Things and artificial intelligence. The article [4] substantiates that the Internet of Things and artificial intelligence are key tools in innovation. In particular, attention is focused on integrating these technologies into the agricultural and service sectors (for example, trade), which is essential for sustainable development. The main benefit can be obtained from increasing productivity, reducing losses, and adapting offers to individual customer needs. The authors consider the efficiency of enterprises, but the energy component is not fully considered.

Formulating the purposes of the article. Identify the main components of the energy efficiency issues of systems based on artificial intelligence of the Internet of Things (AIoT).

Presentation of the main research material. In the article, Naomi A. and co-authors [5] propose a Digital Twin infrastructure that supports a flexible AI-based Internet of Things (AIoT) system for intelligent fish farming in aquaculture. This infrastructure includes the Internet of Things, cloud technologies, and artificial intelligence (AI) as its structural components. It is worth noting that the authors identify four primary digital twin services: food automation, physical quantity estimation, environmental monitoring, and health monitoring. Digital twins are entrusted with the functions of optimization, forecasting, and analysis. This is used to make management decisions to optimize profits and production processes. The authors, first, focus on the need for reliable and faster wireless connections to sensors in very remote and dangerous locations. The second component is data storage, management, and processing. Adding artificial intelligence (AI) functionality to IoT infrastructure allows big data to be stored for processing using AI methodologies capable of predictive analysis to provide mechanisms for making informed management decisions.

The authors of this article reveal applied views on the architecture of the machine and deep learning, which are integrated into the functions of artificial intelligence, specifically in a specific industry - an aquaculture farm. They described a prototype system where the training models were tested, validated, and optimized. For the development of AIoT, autonomous flying and underwater drones were proposed for data collection. Additional functionality will provide a modeling environment for advanced planning and placement of equipment. Artificial intelligence in such an integration will prevent possible damage and problems better.

It is worth emphasizing that society has been trying to reduce the economy's energy consumption for decades. The World Bank proposes to use such an indicator as GDP per unit of energy use (constant 2021 PPP $ per kg of oil equivalent) [6]. Of course, the share of energy consumption for artificial intelligence technologies is relatively low. As it turned out, artificial intelligence turned out to be a relatively energy-intensive tool of modern technologies.

The authors [7] note that the AIoT paradigm, based on artificial intelligence technologies, involves additional energy costs and increased carbon emissions, which can become significant with more complex neural architectures. These scientists proposed a new metric based on the energy cost of the AIoT lifecycle (eCAL). Notably, it is suggested that both total energy consumption and energy consumption per bit be considered. This will allow us to distinguish between different algorithms that can be energy-intensive and computationally efficient.

The design of next-generation networks involves a significant increase in the use of artificial intelligence while ensuring seamless interaction between many devices, online services, and software. This increase is associated with the Internet of Things development, where devices are becoming increasingly intelligent. The number of "smart" household appliances at home and "smart" industrial equipment at enterprises is growing. Humanity is already forming and implementing the Smart City concept, where many devices are combined into a system. The use of artificial intelligence is appropriate in "smart" factories for monitoring and optimizing production processes in real-time, predictive maintenance, tracking the life cycle of products, and expanding possibilities for making management decisions.

In the article [8], the research problem is divided into the following four components: (1) architectures, methods, and hardware platforms for AIoT; (2) sensors, devices, and energy approaches to implementing AIoT; (3) communication and network for AIoT; and (4) software for AIoT. The author supports the need to combine AI and edge computing. This can be a key technology for the further development of AIoT. This approach does not require significant computing capabilities because the information from the sensor is deterministic, uniform, and has one or more information delivery channels. Accordingly, the elements of artificial intelligence do not require hardware, which has a high cost. In this case, data processing from the sensor is carried out directly near it, and the results are transmitted to the object management system.

The main methods for ensuring energy efficiency are selecting training methods, hardware improvement, software optimization, network planning, effective model design, and testing of energy consumption with subsequent conclusions for comprehensive improvement. Energy efficiency can be considered in terms of normalized energy, energy for buffering, and energy consumed. However, these indicators are not intended to determine the energy efficiency of a computing system or its parts. The ITU standardized indicator of energy per bit [J/b] in operation [9]. The source states the following: "Unit bit power dissipation (in other words, average power dissipation while handling a data bit) of the deep packet inspection entities of a node" and "General power dissipation (joule)/ general data traffic (bit)".

It is essential to consider the ecological footprint that an AIoT system creates. It is the ecology that perceives the consequences of AIoT functioning. This has long-term consequences, and therefore, scientists have proposed a new metric that estimates the energy cost of the AIoT life cycle (the unit of measurement is the number of dollars per Joule per bit). Long-term consequences involve taking the life cycle into account. For artificial intelligence (including AIoT), this can be in the general sense of receiving information, processing it, and issuing a result. This is the minimum possible description of the life cycle of an artificial intelligence product. It is worth adding that the AI system must already be functioning; that is, there must be hardware, software, and a data transmission network. The above shows the complexity of AIoT systems. Therefore, the methodology for determining AIoT energy efficiency must evaluate data processing, collection, storage, pre-processing, and, most importantly, machine learning, which can be the most energy-intensive.

Figure 1 shows the set of data processing components involved in the life cycle of an AIoT system, a comparison of energy consumption in different data processing components throughout this cycle, and energy costs depending on the number of inferences.

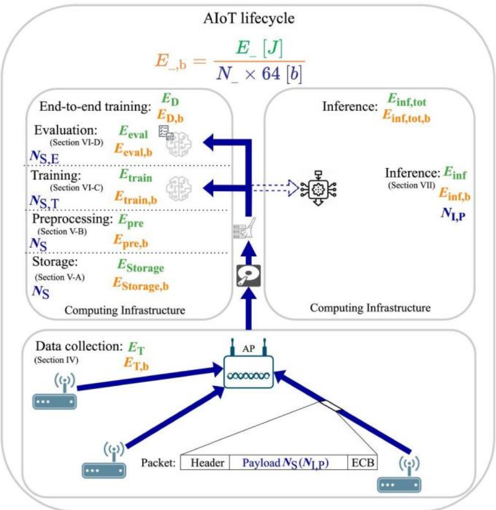

Fig. 1: Data manipulation components involved in the lifecycle of an AIoT system.

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URL: https://arxiv.org/pdf/2408.00540v1

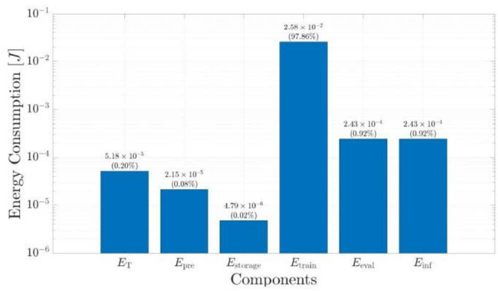

Fig. 9: Comparison of energy consumption in different data manipulation components over the lifecycle of the AIoT model.

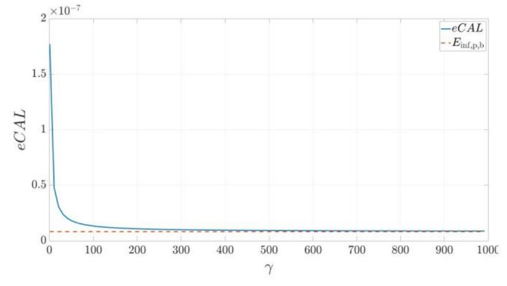

Fig. 12: Energy cost of AIoT lifecycle ($eCAL$) over number of inference (γ).

Figure 1. Usage lifecycle of an AIoT system and energy consumption over number of inference

Source: the figure is based on scientific work [7]

This paper raises the issue of assessing the energy consumption of modern IoT and AI systems in the AIoT product. In the future, this approach will allow us to develop methods that will form economical artificial intelligence systems, information transmission systems, and information storage systems. This will promote competition between artificial intelligence models, particularly in the energy sector. Such competition can lead to a qualitative transition – creating economic artificial intelligence models.

We emphasize that conventionally, fixed and variable costs are distinguished. The conventionally fixed costs include hardware and software and electricity costs for training an artificial intelligence model. The conventionally variable costs include energy consumption per unit of output provided by AIoT. Economists, technologists, and engineers have much to work on to improve the efficiency of future systems.

The conditional variable costs cover the total cost of electricity for generating inference in the AIoT system throughout the entire life cycle of the AI model. Therefore, it is worth developing procedures to minimize energy costs for this cost component. Before that, let us recall that it is worth considering equivalent CO2 emissions for different regions because each locality has its characteristics for electricity generation. In this case, opportunities are open for placing electricity generating capacity for individual AIoT components, such as cloud storage, data processing, etc., near profitable power plants.

Conclusions. The study showed that when integrated with artificial intelligence, the Internet of Things infrastructure creates problems such as increased electricity consumption. The Internet of Things is a modern trend in the development of technology and engineering. That is why the number of IoT devices will grow. Digital twins, faster wireless connection with sensors, and other modern technologies will develop in the future. Integrating artificial intelligence (AI) functionality into the IoT infrastructure provides the opportunity to store big data for processing using artificial intelligence elements capable of conducting predictive analysis to make informed management decisions.

The increasing number of tasks for devices will increase energy consumption. Therefore, a metric based on the energy cost of the AIoT lifecycle (eCAL) is essential. In this cycle, it is worth considering the costs of the following four components: (1) architectures, methods, and hardware platforms for AIoT; (2) sensors, devices, and energy approaches for implementing AIoT; (3) communication and networking for AIoT; and (4) software for AIoT. It is possible to ensure energy efficiency based on the following: selection of training methods, improvement of hardware, optimization of software, network planning, efficient model design, and testing of energy consumption with subsequent conclusions for comprehensive improvement. In addition, it is worth considering the ecological footprint that the AIoT system creates.

The scientific novelty is a methodological approach to a comprehensive study of the processes of implementing AIoT in technological development based on energy efficiency, considering the cost of energy in the AIoT life cycle (eCAL) and the ecological footprint of AIoT systems.

Further scientific research requires economic and mathematical analysis of production systems formed based on the artificial intelligence of the Internet of Things.

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