Міністерство освіти і науки України

Харківський національний університет радіоелектроніки

Кафедра комп'ютерно-інтегрованих технологій, автоматизації, робототехніки та безпекової інженерії

I Всеукраїнська конференція «Інтелектуальні технології цивільної безпеки та робототехнічні системи аварійно-рятувальних робіт»

I All-Ukrainian Conference "Intelligent Civil Safety Technologies and Robotic Systems for Emergency and Rescue Operations"

ICSTRO

2026

I All-Ukrainian Conference

February 12 - 13, 2026

Kharkiv

УДК: 005:004.896:62-65:338.3

Інтелектуальні технології цивільної безпеки та робототехнічні системи аварійно-рятувальних робіт 2026: матеріали I-ої Всеукраїнська конференція, Харків, 12-13 лютого 2026 р.: тези доповідей / [редкол. І.Ш. Невлюдов (відповідальний редактор)].-Харків: [електронний друк], 2026. – 192 с.

У збірник включені тези доповідей, які присвячені сучасним тенденціям розвитку технологій та засобів моделювання, прогнозування та управління ризиками у сфері цивільної безпеки; техногенна та виробнича безпека: технічні засоби, оцінка ризиків, експертиза; інтелектуальні та робототехнічні системи аварійно-рятувальних робіт; кіберфізичні системи, інформаційна безпека та цифровий захист виробництв; інформаційно-комунікаційні технології в системах управління та моніторингу надзвичайних ситуацій; сталий розвиток, екологічна безпека та соціальна відповідальність у сфері цивільної безпеки; інтелектуальні системи прийняття рішень у сфері цивільного захисту.

Intelligent Civil Safety Technologies and Robotic Systems for Emergency and Rescue Operations 2026: Proceedings of I st All-Ukrainian Conference, Kharkiv, February 12 - 13, 2026: Thesises of Reports / [Ed. I.Sh. Nevlyudov (chief editor).] .- Kharkiv .: [electronic version], 2026. - 192 p.

The collection includes the thesises of reports on devoted to current trends in the development of technologies and tools for modeling, forecasting, and risk management in the field of civil safety; industrial and technological safety, including technical means, risk assessment, and expert evaluation; intelligent and robotic systems for emergency and rescue operations; cyber-physical systems, information security, and digital protection of industrial facilities; information and communication technologies in emergency management and monitoring systems; sustainable development, environmental safety, and social responsibility in the field of civil safety; and intelligent decision-support systems in civil protection.

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Державне підприємство «Південний державний проектно-конструкторський та науково-дослідний інститут авіаційної промисловості»
Головне управління ДСНС України у Харківській області

Всеукраїнська конференція «Інтелектуальні технології цивільної безпеки та робототехнічні системи аварійно-рятувальних робіт» (ICSTRO-2026)

All-Ukrainian Conference “Intelligent Civil Safety Technologies and Robotic Systems for Emergency and Rescue Operations” (ICSTRO-2026)

ЗМІСТ

THE CONCEPT OF A DIGITAL TWIN AS A VIRTUAL COPY OF PHYSICAL OBJECTS, PROCESSES, AND SYSTEMS

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***Annotation*:** The work examines the concept of the digital twin as a modern technology for creating a virtual copy of a physical object, process, or system. A five-level architecture of the digital twin is analyzed, which includes the physical level, data collection level, communication level, digital level, and analytical level, as well as the principles of their interaction. A comparative analysis of the digital twin with traditional modeling approaches is conducted based on criteria such as data updating, connection with the object, lifecycle, and forecasting capabilities. Practical examples of using Digital Twin in industry, construction, and smart cities are considered, identifying the main tasks for each sector. Modern software platforms for creating digital twins, including Azure Digital Twins, AWS IoT TwinMaker, and Siemens MindSphere, are analyzed. The main advantages and disadvantages of the technology are identified, as well as the prospects for its further development in the context of Industry 4.0 with the use of artificial intelligence and machine learning.

***Key words*:** Digital Twin, digital twin, Industry 4.0, IoT, automation, data analytics.

КОНЦЕПЦІЯ ЦИФРОВОГО ДВІЙНИКА ЯК ВІРТУАЛЬНОЇ КОПІЇ ФІЗИЧНИХ ОБ’ЄКТІВ, ПРОЦЕСІВ І СИСТЕМ

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***Анотація*:** У роботі розглянуто концепцію цифрового двійника як сучасної технології створення віртуальної копії фізичного об'єкта, процесу або системи. Проаналізовано п'ятирівневу архітектуру цифрового двійника, що включає фізичний, рівень збору даних, комунікаційний, цифровий та аналітичний рівні, а також принципи їх взаємодії. Проведено порівняльний аналіз цифрового двійника з традиційними підходами до моделювання за критеріями оновлення даних, зв'язку з об'єктом, життєвого циклу та можливостей прогнозування. Розглянуто практичні приклади застосування Digital Twin у промисловості, будівництві та розумних містах з визначенням основних задач для кожної галузі. Проаналізовано сучасні програмні платформи для створення цифрових двійників, зокрема Azure Digital Twins, AWS IoT TwinMaker та Siemens MindSphere. Визначено основні переваги та недоліки технології, а також перспективи її подальшого розвитку в умовах Industry 4.0 з використанням штучного інтелекту та машинного навчання.

***Ключові слова*:** Digital Twin, цифровий двійник, Industry 4.0, IoT, автоматизація, аналітика даних.

The rapid development of information technologies, the growth of data volumes, and the increasing complexity of technical systems have led to the emergence of the Industry 4.0 concept, which involves integrating physical processes with digital technologies [1-10]. Within this approach, cyber-physical systems, the Internet of Things (IoT), cloud computing, and artificial intelligence play a particularly important role [11-15]. One of the most promising technologies that combines these directions is the Digital Twin.

A digital twin is not just a static model of an object, but a dynamic virtual replica that is constantly updated based on data from the real environment [16, 17]. Unlike traditional CAD or simulation models, a Digital Twin enables real-time monitoring of the object's condition, analysis of its behavior, and prediction of potential failures or changes in parameters.

The relevance of researching Digital Twin technology is driven by the need to improve the efficiency of operating complex systems, reduce maintenance costs, and increase safety levels. The application of digital twins already demonstrates positive results today in industry, construction, and urban infrastructure management, making this topic important for further scientific research.

Digital Twin is a virtual model of a physical object, process, or system that synchronizes with the real prototype through data streams. The main feature of a digital twin is the two-way connection between the physical and digital environments: data from the real object updates the model, and the results of analysis can be used for management decision-making. Let's imagine a typical Digital Twin architecture includes the following main levels (Fig. 1).

The diagram in Fig. 1 illustrates the interaction of a physical object with a digital model through sensors, communication channels, and analytical modules, enabling monitoring and prediction of the system's condition.

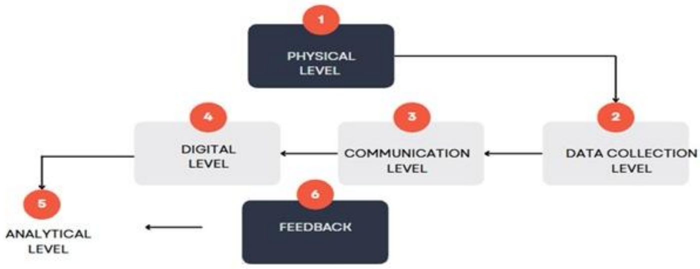

Figure 1 – Digital Twin Architecture

In Fig. 1, the levels are: 1. Physical level – the real object or system (machine, building, transport hub); 2. Data collection level – sensors and/or devices that record operational parameters; 3. Communication level – networks for transmitting collected data using wired or wireless technologies; 4. Digital level – mathematical and simulation models of systems; 5. Analytical level – algorithms for data processing (artificial intelligence, machine learning). For clarity, a Digital Twin can be compared with traditional modeling approaches. Classical models are mainly used at the design stage, whereas a digital twin accompanies the object throughout its entire life cycle (Table 1).

Table 1 – Comparison of Digital Twin and traditional models

Criterion	Traditional models	Digital Twin
Data update	Static, not updated	Dynamic, real-time
Connection with the object	One-way	Two-way
Lifecycle	Design phase	Full lifecycle
Forecasting	Limited	Predictive analytics
Decision making	Manual	Data-driven

Thus, the use of a Digital Twin provides a fundamentally new level of interaction with physical objects. Unlike traditional models, a digital twin not only allows for analyzing the system's state but also actively influences its operational processes through adaptive management and the prediction of critical situations (Table 2). The Digital Twin technology is universal in nature and can be applied in various industries.

Table 2 – Comparative analysis of the use of Digital Twin in various industries

Industry	Main tasks	Practical examples
Industry	Equipment condition monitoring, failure prediction	Predictive maintenance, optimization of production lines
Construction	Structural condition analysis, lifecycle management	Integration with BIM, monitoring building deformations
Smart cities	Infrastructure optimization, resource management	Modeling of traffic flows, energy systems

In the industry, Digital Twin allows for reduced equipment downtime and increased productivity. For example, by analyzing data from sensors, it is possible to detect hidden defects at early stages and schedule maintenance before emergency situations occur. In construction, digital twins are used to assess structural loads, analyze material wear, and predict the lifespan of buildings. In the context of smart cities, Digital Twin enables the modeling of various infrastructure development scenarios, which supports informed management decisions. In construction, digital twins ensure the safety and durability of structures. In smart cities, the technology is used for comprehensive infrastructure management.

Table 3 – Advantages and disadvantages of Digital Twin

Advantages	Disadvantages
Real-time monitoring	High implementation cost
Fault prediction	Complex integration with existing systems
Reduction of operating costs	Need for large amounts of data
Improvement of system reliability	Increased cybersecurity requirements

Thus, the implementation of a Digital Twin is primarily advisable for complex and critically important systems, where the benefits outweigh the costs.

For the practical implementation of the Digital Twin concept, several powerful software platforms are available on the market, providing comprehensive tools for creating, managing, and analyzing digital twins. Among the most common and recognized solutions are Microsoft's Azure Digital Twins, Amazon's AWS IoT TwinMaker, and Siemens MindSphere.

Azure Digital Twins is a cloud-based, model-oriented platform. It enables the creation of spatial graphs of physical environments using standardized ontological models based on the DTDL (Digital Twins Definition Language). This approach ensures semantic interoperability and allows for effective modeling of complex relationships between objects and events in real time. Deep integration with other Azure services, such as IoT Hub, Time Series Insights, and Azure Maps, makes this platform especially effective for smart buildings, urban infrastructure, and logistics.

AWS IoT TwinMaker, in contrast, offers a data- and visualization-driven approach. The platform focuses on rapidly building digital twins by unifying data from various sources, including IoT sensors, video cameras, and business applications. Its distinctive feature is a convenient toolkit for creating interactive 3D scenes and dashboards without requiring deep programming knowledge. This significantly simplifies deployment for monitoring and managing physical assets in industrial enterprises, emphasizing practical visualization of system states.

Siemens MindSphere represents a broader cloud-based IoT operating system designed for industrial applications. It is not just a digital twin platform but a comprehensive environment for collecting, processing, and analyzing data from industrial equipment. It stands out with its support for industrial communication protocols, the availability of powerful built-in analytical tools including machine learning, and deep integration with the Siemens automation ecosystem. Therefore, MindSphere is the top choice for implementing predictive maintenance, optimizing production processes, and monitoring energy efficiency in the context of Industry 4.0. In addition to these three leaders, other specialized solutions exist on the market, such as PTC ThingWorx with its focus on CAD integration, or GE Digital. The choice of a specific platform depends on the tasks at hand, the existing infrastructure, and industry requirements; however, Azure Digital Twins, AWS IoT TwinMaker, and Siemens MindSphere remain the foundational pillars shaping this dynamic market. The study provides a comprehensive analysis of Digital Twin technology as one of the key tools of digital transformation in the context of Industry 4.0. The conceptual foundations of the digital twin, its architecture, and operating principles that ensure continuous data exchange between the physical object and its digital model are considered. Based on a comparative analysis, it was established that the Digital Twin significantly surpasses traditional modeling approaches due to its dynamism, real-time capabilities, and use of predictive analytics methods. Research on application areas has shown the effectiveness of using digital twins in industry, construction, and smart cities, where they contribute to increasing system reliability, optimizing resources, and reducing operational costs. Thus, Digital Twin technology is a promising direction in the development of modern cyber-physical systems and has significant potential for further implementation using artificial intelligence, machine learning, and intelligent data analytics.

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