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

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Інтелектуальні технології цивільної безпеки та робототехнічні системи аварійно-рятувальних робіт 2026: матеріали І-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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All-Ukrainian Conference “Intelligent Civil Safety Technologies and Robotic Systems for Emergency and Rescue Operations” (ICSTRO-2026)

ЗМІСТ

COMPARATIVE ANALYSIS OF INDUSTRIAL DATA TRANSMISSION PROTOCOLS (IIoT) IN AUTOMATION SYSTEMS

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***Annotation*:** This work presents a comparative analysis of key data exchange protocols used in modern automation systems. The advantages and disadvantages of protocols such as Modbus TCP, OPC UA, and MQTT were examined and compared in terms of efficiency, security, and implementation complexity within the context of Industry 4.0. The results of the analysis enable the identification of the most suitable communication standards for different levels of the automation pyramid, which can be useful for system integrators and developers.

***Key words*:** Industry 4.0, automation, IIoT, Modbus TCP, OPC UA, MQTT.

ПОРІВНЯЛЬНИЙ АНАЛІЗ ПРОМИСЛОВИХ ПРОТОКОЛІВ ПЕРЕДАЧІ ДАНИХ (IIoT) В СИСТЕМАХ АВТОМАТИЗАЦІЇ

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***Анотація*:** У цій роботі проведено порівняльний аналіз ключових протоколів обміну даними, що використовуються в сучасних системах автоматизації. Було досліджено та зіставлено переваги й недоліки таких протоколів, як Modbus TCP, OPC UA та MQTT, з погляду ефективності, безпеки та складності реалізації в умовах Industry 4.0. Результати аналізу дають змогу виявити найбільш підходящі комунікаційні стандарти для різних рівнів піраміди автоматизації, що може бути корисним для системних інтеграторів та розробників.

***Ключові слова*:** Industry 4.0, автоматизація, IIoT, Modbus TCP, OPC UA, MQTT.

With the development of robotics and the widespread implementation of cyber-physical systems in the modern industrial world, encompassed by the Industry 4.0 phenomenon, the use of reliable and fast data transmission channels is becoming increasingly common [1-10]. These systems are widely used in various areas such as manufacturing, energy, smart warehouses, and many others [11-15]. One of the key aspects of their operation is the ability to effectively transmit telemetry and control signals between the field level (sensors, PLCs) and the control level (SCADA, ERP). Data transmission protocols, such as Modbus or OPC UA, provide methods to address equipment compatibility issues. However, considering various requirements (real-time operation, cloud computing, low energy consumption), there is a need to analyze these standards to achieve optimal results. A comparative analysis of automation protocols is becoming relevant in the context of Industry 4.0 development. It is necessary to identify the most effective solutions that will improve the quality and speed of information exchange, ultimately leading to increased productivity and efficiency of automation systems. The aim of this study is to conduct a comparative analysis of protocols (Modbus TCP, OPC UA, MQTT) to determine the most suitable variations for specific application conditions.

The purpose of this study is to conduct a comparative analysis of protocols (Modbus TCP, OPC UA, MQTT) to identify the most suitable variants for specific application conditions. To carry out a proper comparative analysis, it is necessary to examine in detail the architecture and operating principles of the selected communication standards.

Modbus TCP is an adaptation of the classic serial Modbus protocol for operation over Ethernet networks (TCP/IP stack). It remains the de facto standard in industrial automation due to its openness and ease of implementation. This architecture operates on a «Client-Server» scheme, formerly known as «Master-Slave». In it, the client, such as a SCADA system or PLC master, initiates a request, to which the server, in the form of a sensor or input/output module, sends a response. The data model provides for storing information in four tables: Discrete Inputs – discrete inputs, read-only; Coils – discrete outputs, read/write; Input Registers – input registers, 16-bit, read-only; Holding Registers – storage registers, 16-bit, read/write. The features of the Modbus TCP protocol lie in the fact that it does not carry information about data types (float, string, int); the interpretation of «raw» bytes is entirely up to the system developer (which requires manually creating memory maps), and the lack of built-in encryption and authentication makes it vulnerable in open networks.

Next, let's consider OPC UA (IEC 62541) – a modern, platform-independent data exchange standard designed to ensure secure and reliable interaction, ranging from embedded devices to cloud systems. The architecture supports both the «Client-Server» model and the «Publisher-Subscriber» (Pub/Sub) model in newer specifications, and the main distinction from its predecessors is a service-oriented architecture (SOA). Unlike the «flat» addressing space of Modbus, OPC UA uses a graph structure of nodes, where each node contains not only a value but also metadata such as units of measurement, timestamps, and access rights, as well as semantic relationships with other objects, enabling the concept of self-describing devices. The OPC UA protocol has built-in security measures at the transport and application layers, including encryption using AES and RSA algorithms, user and application authentication based on X.509 certificates, as well as message integrity checks.

Another protocol is MQTT, which is a lightweight network protocol that operates over TCP/IP and is optimized for networks with low bandwidth, high latency, or unreliable connections. It has become a key standard for the Internet of Things (IIoT). The system architecture is based on the Publish/Subscribe model, where a broker provides the connection. Client devices are not directly connected to each other. They publish messages to specific topics, and the broker distributes them to all subscribers, ensuring complete decoupling of system components in space and time.

The MQTT protocol offers three levels of Quality of Service (QoS), allowing flexible configuration of delivery reliability: QoS 0 (At most once) – no delivery guarantee; QoS 1 (At least once) – guaranteed delivery, duplicates possible; QoS 2 (Exactly once) – guaranteed delivery without duplicates (most resource-intensive). MQTT features include its ability to be payload agnostic, meaning it can transmit both text (JSON, XML) and binary data without defining their structure. For data standardization in the industry, the Sparkplug B specification is often applied on top of MQTT. Based on the conducted research, a comparison of the advantages and disadvantages of the considered automation protocols was carried out, and the comparison results are presented in Table 1.

Table 1 – Comparison of the advantages and disadvantages of automation protocols

Protocol	Advantages	Disadvantages
Modbus TCP	Ease of implementation and wide support by all PLC manufacturers. Minimal overhead for packet headers.	Lack of built-in security (encryption). The need to manually locate register addresses.
OPC UA	High security (certificates), semantic data compatibility, availability of subscription, and history mechanisms.	High implementation complexity. Requires significant CPU computing resources.
MQTT	Efficient use of traffic, event-driven operation, ideal for cloud solutions (IIoT).	Lack of a standardized data structure (payload agnostic). Risk of data loss without QoS configuration.

A comparative analysis of the efficiency of industrial data transmission protocols is shown in Fig. 1. Based on Figure 1, several important conclusions can be drawn regarding the performance characteristics of the three industrial protocols. Modbus TCP demonstrates the most efficient resource utilization, consuming minimal CPU power at only 3 %, requiring just 2 MB of memory, and maintaining a low latency of 5 ms with a compact message overhead of 12 bytes.

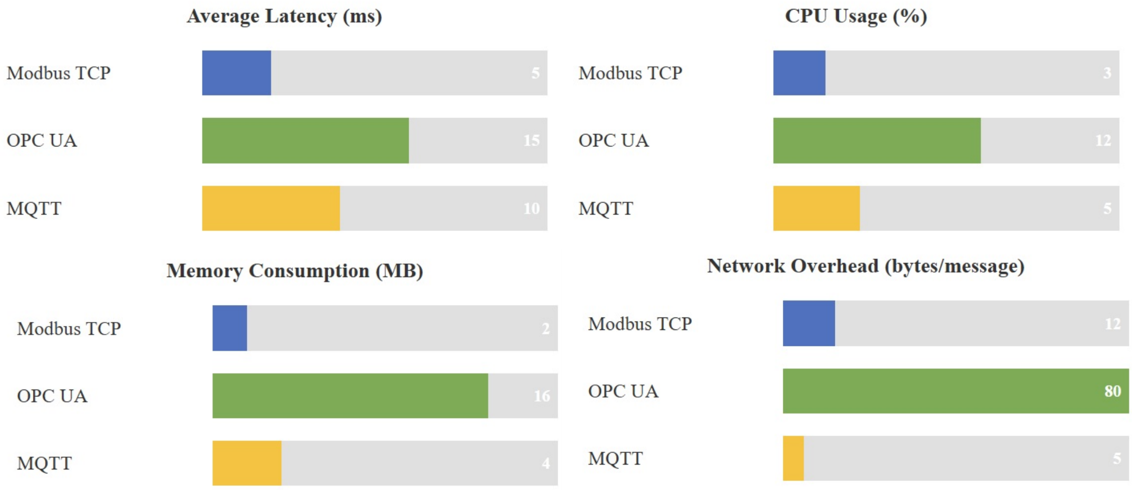

Figure 1 – Comparative performance analysis of industrial data transmission protocols

These characteristics make it an excellent choice for resource-constrained embedded systems and applications where simplicity and speed are paramount. However, its throughput is limited to 1000 messages per second, and it can handle only 247 concurrent connections, which restricts its scalability.

In contrast to Modbus, OPC UA is a much more resource-intensive protocol, requiring more computing power, memory, and generating the highest network load. However, these costs are fully justified at the enterprise level, as the protocol provides built-in security, semantic data modeling, and the ability to support thousands of simultaneous connections for integrating complex systems.

MQTT, on the other hand, offers a balanced approach, ideal for IoT. It demonstrates outstanding throughput and support for tens of thousands of connections, while having minimal overhead and moderate resource consumption. This efficiency, along with the publisher-subscriber model, makes it an optimal choice for cloud and distributed architectures, where scalability and network bandwidth efficiency are critical.

This work presents a comparative analysis of the three main data transmission protocols used in modern industrial automation systems: Modbus TCP, OPC UA, and MQTT. The study of the architecture, operating principles, and key characteristics of these protocols made it possible to identify their specific advantages and limitations in the context of Industry 4.0.

The analysis results demonstrated that Modbus TCP remains the optimal choice for resource-constrained lower-level automation systems, where simplicity of implementation, minimal resource consumption, and low latency are critical. The protocol provides efficient operation in local networks between PLCs and field devices, but requires additional security measures when used in open network environments. OPC UA proved to be most suitable for vertical integration of heterogeneous systems at the enterprise management level, where semantic data compatibility, high security, and the ability to work with complex information models are required. Despite significant computational resource requirements, the protocol ensures reliable interaction between SCADA systems, MES, and ERP levels thanks to built-in encryption, authentication, and metadata support mechanisms. The analysis results demonstrated that Modbus TCP remains the optimal choice for resource-constrained lower-level automation systems, where simplicity of implementation, minimal resource consumption, and low latency are critical. The protocol provides efficient operation in local networks between PLCs and field devices, but requires additional security measures when used in open network environments. OPC UA proved to be most suitable for vertical integration of heterogeneous systems at the enterprise management level, where semantic data compatibility, high security, and the ability to work with complex information models are required. Despite significant computational resource requirements, the protocol ensures reliable interaction between SCADA systems, MES, and ERP levels thanks to built-in encryption, authentication, and metadata support mechanisms.

REFERENCES

1. Andreiev A. S., Sotnik S. V. Analysis of robotics platforms for educational and research purposes. Комп'ютерні ігри та мультимедіа як інноваційний підхід до комунікації - 2024 / Матеріали IV Всеукраїнської науково-технічної конференції молодих вчених, аспірантів і студентів, Одеса, 26-27 вересня 2024 р., 2024. PP. 25-27

2. Bielik, M. S. & et al.. Analysis of the structures of mobile platforms for promoter robots. The 5th International scientific and practical conference "Global trends in science and education" (June 2-4, 2025) SPC "Sci-conf.com.ua", Kyiv, Ukraine, 2025. PP. 319-325

3. Sotnik, S. & et al.. Evaluating relational database scaling strategies in web engineering. International Conference on Advanced Trends In Radioelectronics and Infocommunications (ATRIC-2025) (May 21–22, 2025), Lviv Polytechnic Publishing House, Lviv, Ukraine, 2025. PP. 224-228

4. Yechevskyi, A. D. & et al.. Research of orientation methods of autonomous mobile robots in industrial conditions, «Computer-integrated technologies, automation and robotics» CITAR-2025, 2025. PP. 115-119

5. Sukhomlinova, D.A. & et al.. Aerial robot in urban environments. Sustainable smart cities and communities: business and innovation solutions 2025: Proceedings of I st I International Conference, Kharkiv, April 21, 2025: Thesises of Reports, 2025. PP. 45-46

6. Shrubkovskyi, Y. V. & et al.. Development of a structural scheme for automatic dosing of liquid components. Період трансформаційних процесів в світовій науці: задачі та виклики: збірник наукових праць з матеріалами V Міжнародної наукової конференції, м. Кропивницький, 6 червня, 2025 р. / Міжнародний центр наукових досліджень. – Вінниця: ТОВ «УКРЛОГОС Груп, 2025. PP. 242-246

7. Zarubin, I. & et al.. Basic principles of building aerial robots. Manufacturing & Mechatronic Systems 2024: Proceedings of VIII st International Conference, Kharkiv, October 25-26, 2024. PP. 32-36

8. Lashyn, Z. V. & et al.. Automation capabilities of equipment with built-in robot for manufacture of microelectronics products. Proceedings of the XVII International scientific and practical conference «Information technologies and automation – 2024», 2024. PP. 283-286

9. Lykho, T. A. & et al.. Pattern recognition and computer vision technologies in decision support systems of robotic systems. Proceedings of the XVII International scientific and practical conference «Information technologies and automation – 2024», 2024. PP. 645-648

10. Andreiev A. S. & et al.. Comparative analysis of robotics platform: Webots, Coppeliasim and Gazebo. Сучасні проблеми і досягнення в галузі радіотехніки, телекомунікацій та інформаційних технологій: Тези доповідей XII Міжнародної науково-практичної конференції (10-12 грудня 2024 р., м. Запоріжжя). [Електронний ресурс] /Електрон. дані. – Запоріжжя, 2024. PP. 96-100

11. Nevludov, I. Sh. & et al. Application of artificial intelligence in additive manufacturing (3D printing). Information Technologies and Automation – 2025 / Proceedings of the XVIII International Scientific and Practical Conference. Odessa, October 30-31, 2025. – Odessa, ONUT Publishing House, 2025. PP. 1006-1009

12.Marunich, R.V., Sotnik, S.V. Modern IoT technologies for creating automated access systems. Sustainable smart cities and communities: business and innovation solutions 2025: Proceedings of I st I International Conference, Kharkiv, April 21, 2025: Thesises of Reports, 2025. PP. 38-39

13. Marunich, R.V. & et al.. Features of IoT application in the security sector. «Computer-integrated technologies, automation and robotics» CITAR-2025, 2025. PP. 80-84

14. Marunich, R., & et al.. Approaches to ensuring the effective implementation of IoT technologies in various industries. International Conference «DIGITAL INNOVATION & SUSTAINABLE DEVELOPMENT 2024», 2024. PP. 22-23

15. Sotnik, S. Integration of IoT into security systems: opportunities and risks. International Journal of Academic Engineering Research (IJAER), 2024. PP. 56-61