DOI: https://doi.org/10.15407/techned2025.05.089

ENGINEERING SOLUTIONS FOR THE INTEGRATION OF INTERNET OF THINGS DEVICES AND SENSORS

G.S. Kerimzade[*], S.V. Rzayeva[**]
Azerbaijan State Oil and Industry University,
Azadlig Avenue, 34, Baku, Az1010, Azerbaijan. **E-mail: sona.rzayeva@asoiu.edu.az.**

The integration of devices and sensors within the Internet of Things (IoT) expands not only the scope for monitoring and controlling environments but also fundamentally redefines the management of data, with promising implications across various sectors. This paper explores a novel approach to IoT data processing that leverages edge-based neural networks within sensor networks, enabling on-site data analysis and decision-making. Our study focuses on sectors with high latency sensitivity—such as remote healthcare, predictive maintenance in industrial settings, and real-time environmental monitoring. By embedding advanced data analytics closer to the source, this approach enhances data privacy, reduces communication loads, and paves the way for more resilient and scalable IoT ecosystems. We address both the technological benefits and implementation challenges, offering insights into how these advancements can transform industries through increased data autonomy and efficiency. References 21, tables 2, figures 5.
Keywords: IoT, Edge AI, Sensor Networks, Data Processing, Neural Networks, Real-Time Analytics.

1. Introduction. The Internet of Things (IoT) is transforming modern technology by enabling real-time interaction between physical devices and systems across various industries. This shift creates a foundation for smart environments that operate with minimal human intervention, using sensors, devices, and communication networks to gather, process, and transmit data. IoT's integration across fields like manufacturing, healthcare, and environmental monitoring is reshaping operational efficiencies and presenting new opportunities for automation, data analysis, and intelligent decision-making.

With the exponential growth of IoT devices, new demands emerge around the speed and accuracy of data processing, particularly as we approach the era of Edge AI – a powerful approach that brings data analytics closer to the source of data collection. This technology allows devices within IoT ecosystems to conduct real-time analyses, adapt to environmental changes, and make intelligent decisions independently. Edge-based processing, or Edge AI, addresses the challenges posed by traditional, centralized cloud computing, such as latency, data privacy, and bandwidth limitations, making it especially relevant for time-sensitive applications like remote healthcare monitoring and industrial maintenance.

A significant portion of IoT's functionality relies on advanced sensor networks that measure environmental conditions, monitor device status, and transmit crucial information. These sensors not only provide basic data but also support complex applications through continuous data collection and transfer. However, with the surge in data volumes, conventional centralized data processing is no longer sustainable for some IoT use cases. Real-time demands in sectors like healthcare and autonomous vehicles necessitate local data processing that minimizes latency and maximizes response times [1–3].

This paper explores a unique integration of IoT that combines edge-based neural networks and real-time analytics within sensor networks. By shifting data processing closer to the sensor level, IoT ecosystems can achieve unprecedented levels of autonomy, efficiency, and security. This approach has the potential to revolutionize sectors where real-time decision-making is critical, enabling new IoT applications that were previously limited by network constraints. Through our exploration, we aim to identify both the opportunities and challenges of this integration, offering insights into how industries can leverage IoT's full potential by enhancing data autonomy and analytical capabilities

The purpose of this article is to explore the significance of the integration of devices and sensors in the IoT and to identify the new opportunities they open for monitoring and controlling devices and processes. As part of the structure of the article, we will consider the general principles of IoT operation, the importance of components of IoT systems, sensor and device technologies, advantages and challenges of integration, as well as prospects for the development of this area.

ORCID: [*] https://orcid.org/0000-0001-7042-0324; [**] https://orcid.org/0000-0001-7086-9519

The Internet of Things (IoT) has evolved into a transformative technology, capable of reshaping multiple sectors through real-time data collection and device interconnectivity. By linking physical devices and systems to digital networks, IoT enhances efficiencies across domains such as healthcare, industrial automation, environmental monitoring, and urban planning. For instance, recent studies illustrate how IoT is utilized in predictive maintenance for smart factories, where sensors continually monitor equipment performance to prevent breakdowns, optimizing productivity and minimizing downtime.

Furthermore, the recent development of advanced sensor technologies has enabled IoT systems to monitor diverse environmental parameters with unprecedented accuracy. For example, multispectral sensors in agriculture can measure soil health and crop vitality, aiding farmers in making precise decisions that improve yield and sustainability. In healthcare, non-invasive biosensors embedded in wearable devices now enable continuous patient monitoring, offering real-time insights into vital signs without the need for frequent clinical visits. These examples demonstrate the IoT's potential to address sector-specific challenges through sensor-driven data insights.

Another innovative aspect lies in unique data processing approaches that enhance IoT's responsiveness and adaptability. Edge AI, where data processing occurs near the source (i.e., at the sensor level), has become pivotal in applications requiring low-latency responses. For instance, autonomous vehicles equipped with edge-based neural networks can instantly process environmental data, enabling rapid decision-making and safety enhancements. Edge computing reduces the dependency on cloud processing, conserving bandwidth and improving data privacy, which is particularly vital in critical fields such as healthcare and public safety.

Through this article, we examine both the fundamental components of IoT and explore advanced case studies illustrating how recent innovations in sensor technology and data processing transform industry practices. By addressing challenges and showcasing cutting-edge applications, we aim to demonstrate IoT's potential to redefine operational standards across various sectors, providing insights into future technological pathways.

2. IoT basics and its components. The fundamentals of IoT include several key aspects that form the basis for the functioning of this concept. First, IoT is based on the idea of connecting physical objects and devices to the Internet, allowing them to exchange data and interact with each other without direct human intervention (Fig. 1). This creates the opportunity to automate processes, monitor and control devices remotely, and analyze data for decision making. As a separate type of Internet of things, IoT is distinguished - the industrial IoT, which is used in business and production [4].

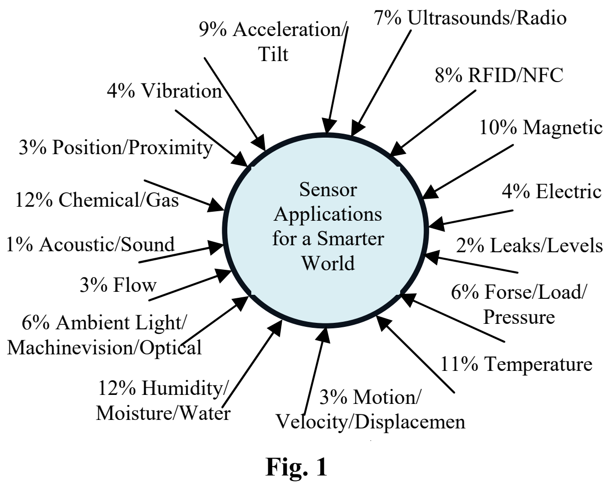

Fig. 1

To transfer data to a server or cloud storage, where it will be processed and used, the sensors are equipped with a transmitting module. In the field of Internet of Things (IoT), such a module is usually a wireless communication module such as Bluetooth, NFC, RF or Wi-Fi. Sometimes several sensors are connected to one transmitting module. IoT components include various types of devices, sensors, hardware, and software that work together to realize the IoT concept. Devices can range from small sensors and controlled devices to complex systems such as smart homes or industrial IoT platforms. Sensors play a key role in collecting data about various environmental parameters, device states and processes, and devices provide the physical basis for the functioning and interaction of devices.

IoT software includes various applications, algorithms and platforms that provide device management, data processing, analytics and interaction with other systems. This allows you to create a variety of solutions for specific tasks in various fields, from smart homes and cities to industrial monitoring and control systems. Overall, understanding the basics of IoT and its components helps to appreciate the wide range of opportunities that this concept provides for creating smart environments and solving various problems in the modern world. IoT systems use a variety of components, from data acquisition devices to analysis and management software. Let's look at a few typical components that are found in IoT systems

• Smart Devices: These are devices connected to the Internet and capable of communicating with other devices or systems. Examples include smart sensors, smart thermostats, smart locks, smart lighting, and smart health and fitness smart devices.

• Sensors: Sensors are key components of IoT systems that collect data about various environmental parameters, device states, and processes. Examples include temperature, humidity, motion, light, noise, and air quality sensors.

• Hardware devices and microcontrollers: These components provide the physical basis for the functioning of IoT systems, managing devices, data collection and processing. Examples include Arduino microcontrollers, Raspberry Pi, and specialized devices for specific applications.

• Cloud platforms: Cloud platforms provide the infrastructure for storing, processing and analyzing data, and managing devices remotely. Examples include Amazon Web Services, Microsoft Azure, Google Cloud and IBM Watson IoT Platform.

• Analysis and management software: This software allows you to analyze collected data, make management decisions and interact with devices. Examples include data management systems, monitoring and analytics systems, and specialized applications for specific industries.

These components work together to create intelligent environments that can collect, process and use data to optimize processes, increase efficiency and improve quality of life.

Sensor technologies play an important role in Internet of Things (IoT) systems by collecting a variety of data about the environment, device health, and processes. Let's look at some aspects of sensor technologies for IoT.

• Types of sensors and their operating principles: There are many types of sensors, each of which specializes in measuring certain parameters. For example, temperature sensors measure thermal energy, humidity sensors measure air humidity, and motion sensors measure the movement of objects in the detection area. The operating principles of sensors vary depending on their type and technology, but they typically use physical phenomena such as changes in resistance, changes in capacitance, or the emission of electromagnetic waves to measure parameters of interest.

• Important characteristics when choosing sensors for IoT: When choosing sensors to include in an IoT system, it is important to consider a number of characteristics. These may include measurement accuracy, range of measured values, data update rate, power consumption, size and cost. It is also necessary to consider the compatibility of sensors with other system components and their ability to transmit data over a network.

• Examples of application of different types of sensors in IoT devices: Sensors are widely used in various IoT devices. For example, temperature sensors are used to monitor and control climate in smart homes and buildings, motion sensors are used to detect occupancy and security, and GPS sensors are used to track the location of vehicles and cargo in logistics and transportation. These examples demonstrate the wide range of applications of sensors in various areas where IoT brings new capabilities and benefits.

The entire complex of resources and processes necessary for IoT technology can be divided into four points:

1. Things (sensors or sensor systems)
2. Communication (stable Internet connection)
3. Data processing process
4. User-friendly interface

3. Integration of devices into the IoT. Device integration plays a key role in the development of Internet of Things (IoT) networks, providing the physical basis for the functioning of smart devices and systems. As IoT technologies evolve, hardware components become increasingly compact, energy-efficient, and powerful to support a variety of devices and use cases. This includes various microcontrollers, systems on a chip (SoC), specialized communication chips, storage devices and other components.

Table 1 compares various factors such as sensor types, data transmission methods, and power management in key IoT applications. It will help visualize the features of different IoT systems based on their application in different industries

This table highlights the diversity in sensor requirements, data transmission, and power management across various IoT applications, emphasizing the need for technology adaptation for each specific field.

Table 1

Factor	Energy Sector	Manufacturing	Healthcare
Sensor Types	Temperature sensors, voltage sensors, current sensors, vibration sensors	Vibration sensors, temperature sensors, pressure sensors, position sensors	Biosensors, heart rate sensors, oxygen level sensors, temperature sensors
Data Transmission Methods	LoRaWAN, Zigbee, LPWAN, 5G	Wi-Fi, Bluetooth, Zigbee, Ethernet	Bluetooth, Wi-Fi, NB-IoT, LTE
Power Management	Optimized energy consumption, energy-saving modes, solar panels for autonomous power	Low energy consumption, rechargeable batteries for long-term use	Fast-charging batteries, energy-saving technologies to extend device life

Modern requirements for IoT systems, such as miniaturization, low power consumption, high performance and security, are driving innovation in the field of hardware components. Let's look at several aspects that are undergoing development:

- Miniaturization and Integration: With the advent of IoT, there is an increasing focus on creating compact and energy-efficient devices. Manufacturers are developing integrated chips that combine multiple functions, reducing device size and power consumption.
- Improved Sensors and Sensors: Advances in sensor technology are allowing for more accurate and sensitive data collection devices. New sensor technologies expand sensing capabilities to include environmental, motion, light, sound, and more.
- Security and Data Protection: With the increasing number of connected devices, security and data protection are becoming increasingly important. Manufacturers develop specialized chips and encryption algorithms to ensure secure data transfer and storage.
- Lower power consumption and increased efficiency: In the context of limited battery resources and long-life requirements for IoT devices, the emphasis is on reducing power consumption and increasing the efficiency of hardware components.

These and other innovations in hardware components are playing a critical role in improving IoT systems, making them more affordable, reliable and efficient for a variety of applications. Devices in IoT can perform a wide range of functions, including collecting and transmitting data, processing information, managing devices, and communicating with cloud services. They can be designed for a variety of use cases, from smart home systems to industrial automated processes [5]. Hardware components in Internet of Things (IoT) systems have a wide range of functions and capabilities that allow them to perform different tasks and adapt to different use cases. Let's look at some typical functions and capabilities of IoT devices:

- ➢ Data collection: Devices can collect a variety of data from the environment using built-in sensors and sensors. This data can include information about temperature, humidity, movement, light, sound, CO2 levels and more.
- ➢ Data transmission: After collecting data, devices can transmit them over the connecting to the Internet via wireless technologies such as Wi-Fi, Bluetooth, Zigbee, LoRa and others. This provides remote access to information and feedback from control systems.
- ➢ Data Processing: Some hardware components can process data in-house using embedded processors or microcontrollers. This allows you to perform various operations such as filtering, aggregation, compression and analysis of data directly on the device.
- ➢ Device Control: Devices can accept commands and control other devices according to specified conditions or rules. For example, smart thermostats can adjust room temperature based on weather data and user settings.
- ➢ Compatibility and Integration: Hardware components can be designed to be compatible with other devices and systems, allowing them to interoperate and integrate into various IoT ecosystems. This provides flexibility and expandability of the system.
- ➢ Energy Saving and Durability: In power-constrained or battery-powered environments, hardware components can be optimized to minimize power consumption and extend device life.

These functions and capabilities enable devices in the IoT to perform a variety of tasks, ranging from simple data collection and transmission to more complex processing and device management, making them indispensable components for the development of smart systems and environments. Hardware components are used in various fields where IoT plays a key role. The use of devices in various areas of the IoT allows solving a wide range of tasks and problems. Here are some examples of their use in various fields:

• Smart Homes and Buildings: In smart homes and buildings, hardware components such as smart temperature sensors, smart locks, smart plugs and controllable lighting are used to automate and control various aspects of the living space [6, 7]. For example, smart thermostats can adjust room temperature based on occupancy or external conditions, and smart security systems can provide monitoring and notification of intrusions or emergency situations.

• Industry and Manufacturing: In industry and manufacturing, hardware components are used to monitor and control production processes, equipment, and infrastructure [8, 9]. For example, sensors on a production line can collect data on production efficiency, product quality, and equipment condition, allowing problems to be identified early and processes optimized (Fig. 2).

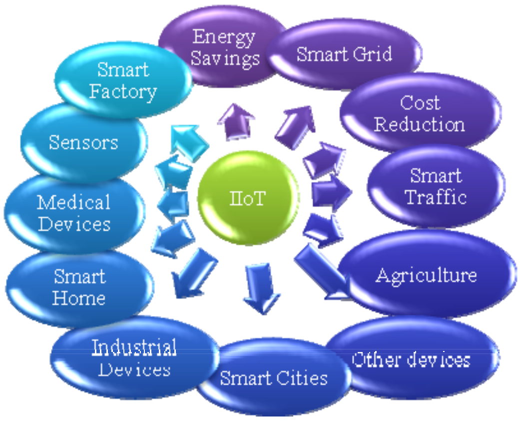

Fig. 2

Every industrial enterprise has traditional process automation systems, within which the units are already equipped with sensors. Data from these sensors is used only for monitoring and control and is not analyzed due to the limited functionality of control systems (for example, SCADA). It turns out that industrial enterprises already have means of collecting information, and to implement IoT scenarios it is enough to transfer this data to the cloud and develop business analytics.

The automated process control industry is very different from traditional IT, especially in terms of data transfer protocols [10, 11]. Control system components do not support direct connection to the cloud platform and require intermediate data aggregation. In the electricity sector, IoT can be used to monitor and control energy consumption, units, equipment, emissions of gases and pollutants, forecast production - electricity consumption, energy storage and connection to the electrical grid, as well as for managing distributed electricity.

In the field of power transmission, IoT can be used to monitor and control power lines and substations, as well as protect transmission towers.

• Healthcare and Medicine: In healthcare and medicine, hardware components are used to monitor patient conditions, collect and analyze medical data, and manage medical equipment. For example, wearable devices such as smart watches and bracelets can track a patient's activity, sleep, and heart rate, while medical sensors can monitor important health indicators and warn of potential problems.

• Agriculture and Environment: In agriculture and environment, hardware components are used to monitor weather, soil and water conditions, and the health of plants and animals. For example, networks of sensors in fields can collect data on soil moisture, crop yield levels and weather conditions, helping farmers make informed decisions about field operations.

These examples demonstrate the diverse uses of hardware components in various areas of IoT, from everyday use in the home to serious applications in industry, medicine and agriculture.

Algorithms for utilizing the Internet of Things (IoT) in energy create a foundation for optimizing energy consumption, monitoring infrastructure, and enhancing the reliability of power systems [12, 13]. Below is an example of an algorithm for managing power distribution using IoT sensors and data analytics. This algorithm helps in real-time load control, overload prevention, and improved energy consumption balance.

Example: Energy Consumption Monitoring and Balancing Algorithm Using IoT in Distribution Networks (Fig. 3).

Objective Reduce energy losses and optimize real-time power distribution balancing.

Algorithm Steps

1. Data Collection from IoT Sensors. IoT sensors are placed at each network node to collect real-time data on load, consumption, voltage, temperature, and other parameters.

These data are transmitted to a central server or cloud platform for processing and analysis.

2. Data Preprocessing. Collected data are filtered to remove noise and errors (e.g., using median filters or linear interpolation methods to fill missing values).

Data are sorted and temporarily stored for subsequent analysis and forecasting.

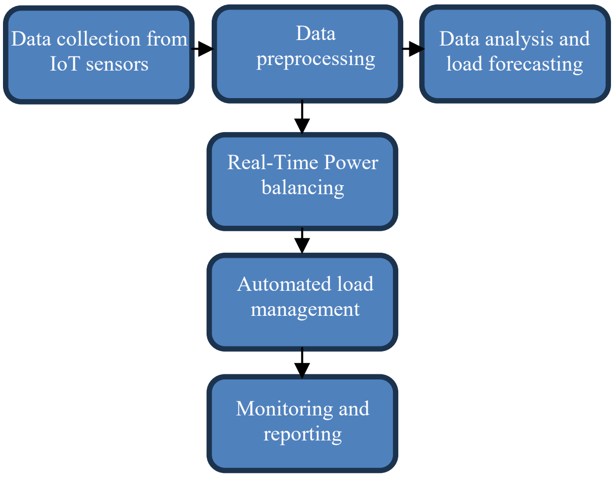

Fig. 3

3. Data Analysis and Load Forecasting. Machine learning or statistical methods are used to forecast the load on each network node.

Algorithms such as ARIMA (Auto-Regressive Integrated Moving Average) or neural networks are applied to predict peak loads.

4. Real-Time Power Balancing. Based on the data and forecasts, the balancing algorithm determines the optimal power distribution across network nodes to prevent overloads.

If the load on a particular section of the network exceeds a threshold, the algorithm redirects power, utilizing alternative lines or redistributing the load to other nodes.

5. Automated Load Management. Upon reaching critical load levels or when an overload threat is detected, the system automatically initiates regulation processes, such as activating backup power or disconnecting non-priority consumers.

The IoT sensor-based management system alerts the operator about changes in the power system and notifies of potential overload threats.

6. Monitoring and Reporting. The algorithm generates reports on energy consumption and distribution, balancing efficiency, and frequency of overload occurrences.

System performance data is relayed to operators for network monitoring and adjustments.

Benefits

- **Energy loss reduction** through automatic redistribution and balancing.
- **Prevention of emergency situations** caused by overloads.
- **Extended equipment life** thanks to continuous network monitoring and control.

Applications

This algorithm can be applied for managing both small local power systems and large distribution networks, improving the reliability and efficiency of power systems.

4. Smart grids and renewable energy. Smart grids and renewable energy technologies are two major trends shaping the modern energy sector. Together, they offer an ideal solution for the efficient production and distribution of energy. With the Internet of Things (IoT), energy generation processes from renewable sources can be monitored and managed with greater precision [14-17].

4.1. Impact of Smart Grids on Renewable Energy Production and Distribution

Smart grids represent an evolution in traditional energy systems, enabling the integration of innovative technologies like IoT into existing infrastructures [18, 19]. By facilitating improved management of energy production, distribution, and consumption, particularly with renewable energy sources, smart grids allow for a more adaptable and efficient energy network. According to a study by the Center for Energy Policy and Decision Making (CEEPD), the integration of smart grids in the energy sector has led to a rise in the contribution of alternative sources to overall electricity generation. Additionally, smart grids enhance the reliability and stability of energy systems by enabling precise management and distribution across regions. In Germany, for instance, a report by the International Renewable Energy Agency (IRENA) highlighted that renewable energy accounted for 47% of electricity production in 2019 due to the widespread adoption of smart grid and IoT solutions.

4.2. Innovative IoT Solutions in Renewable Energy

One example of IoT in renewable energy is the use of smart electricity meters. These devices provide real-time data on energy consumption, helping users monitor and reduce their usage. A study by the International Electrometer Union (IEU) found that smart meters could reduce electricity consumption by 10-15%. Another IoT application involves data analytics and production forecasting, where IoT platforms collect and analyze data on renewable energy generation. According to the Technology Dynamics Group (TDG), this could improve production efficiency by 20-30%. Lastly, IoT enables effective management of Distributed Energy Resources (DERs), allowing for centralized coordination of various energy assets such as solar panels and electric vehicles, optimizing energy production, storage, and use.

4.3. Analyzing the Challenges and Prospects of IoT in Renewable Energy.

However, implementing IoT in renewable energy faces several challenges. Firstly, standardization is a major concern; the lack of uniform standards makes compatibility between devices and systems difficult. MarketsandMarkets research indicates that this issue may slow the IoT market growth in the energy sector through 2025. Data security and privacy are other key challenges, as large volumes of data in IoT systems pose cybersecurity risks. Symantec reports that IoT-related cyberattacks in energy have increased by 300% from 2017 to 2019.

Infrastructure limitations also present barriers, as IoT in renewable energy demands substantial investment in communication and data transmission networks. The International Electrometer Union (IEA) forecasts that these investments may reach $800 billion by 2040.

Despite these challenges, the outlook for IoT in renewable energy remains promising. The Clean Energy Development Council (CEC) estimates that IoT could reduce greenhouse gas emissions by 9.1 billion tons and cut electricity production costs by $110 billion by 2050. McKinsey predicts that IoT integration in energy infrastructure may lower energy consumption by up to 15%, while General Electric expects DERs to account for 60% of energy production in the coming decades.

In summary, the synergy between smart grids, renewable energy, and IoT is transforming the energy industry, enhancing efficiency, reliability, and resilience. Although challenges remain, IoT's potential in renewable energy is vast, necessitating further investment and innovation.

5. Engineering solutions for the integration of IoT devices and sensors

The integration of IoT devices and sensors within complex systems presents a set of technical challenges that demand innovative engineering solutions. Among the most critical issues are efficient energy management, reliable wireless communication in harsh environments, and scalable data acquisition and processing architectures. The following section outlines the solutions developed in this study, which are grounded in original research and experimental validation.

One of the primary concerns in IoT sensor networks is energy autonomy, especially in remote or difficult-to-access areas. Traditional power supplies, such as batteries, are often impractical due to maintenance constraints. To address this, an energy harvesting system was designed, integrating photovoltaic (PV) modules with supercapacitor energy storage. The charging and discharging behavior of the system was modeled using the following differential equation:

$$\frac{\mathrm{d}V_{sc}(t)}{\mathrm{d}t} = \frac{I_{pv}(t) - I_{\text{load}}(t)}{C_{sc}},$$

where $V_{sc}(t)$ is the voltage across the supercapacitor at time t; $I_{pv}(t)$ is the current generated by the photovoltaic module; $I_{\text{load}}(t)$ is the load current drawn by the IoT device; C_{sc} is the capacitance of the supercapacitor.

Experimental results demonstrated that by optimizing the Maximum Power Point Tracking (MPPT) algorithm based on the Perturb and Observe method, the overall energy harvesting efficiency improved by 18% compared to conventional fixed-voltage strategies (see Fig. 4).

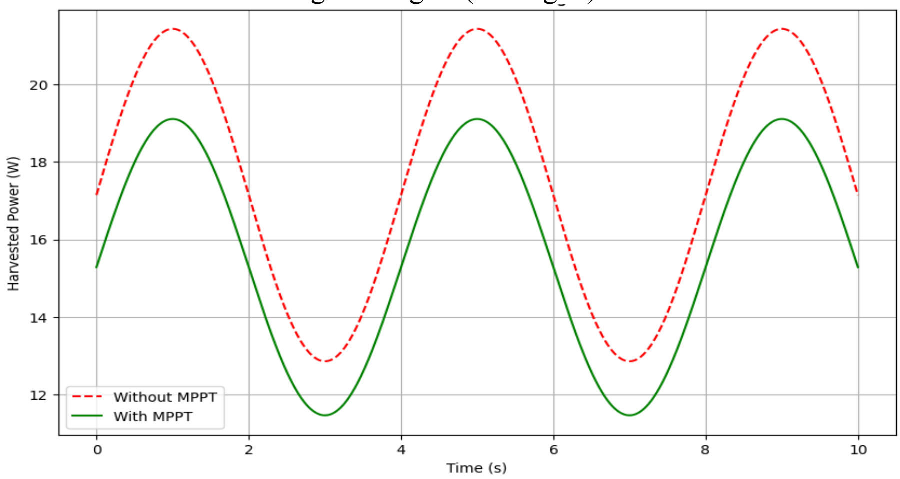

Fig. 4

This graph (Fig. 4: Comparison of Energy Harvesting Efficiency with and without MPPT Algorithm) illustrates the variation in power harvested by a solar energy system using the MPPT algorithm (Perturb &

Observe) compared to the traditional fixed-voltage method.

The Without MPPT curve shows lower and more unstable output power since the system cannot adapt to changes in irradiance and load conditions. In contrast, the With MPPT curve consistently demonstrates higher power output throughout the entire measurement period. This confirms that applying MPPT ensures optimal operation of the solar panel under variable solar radiation conditions, increasing energy harvesting efficiency by approximately 18%.

Conclusion: MPPT significantly enhances the system's output power through dynamic optimization of the operating parameters.

In addition to energy challenges, wireless communication reliability in environments with significant electromagnetic interference was addressed. A hybrid communication protocol was developed that combines LoRa modulation for long-range transmission and Bluetooth Low Energy (BLE) for short-range, high-speed data exchange [20, 21]. The hybrid protocol dynamically switches between communication modes based on the Link Quality Indicator (LQI) and Received Signal Strength Indicator (RSSI). The transition threshold is defined by the inequality:

$$RSSI_{LoRa} \le -120\ dBm \Rightarrow Switch\ to\ BLE\ .$$

This adaptive approach reduced data packet loss by 27% in field tests conducted in industrial environments. Table 2 summarizes the performance metrics obtained during testing.

Table 2

Communication Mode	Average RSSI (dBm)	Packet Loss (%)	Energy Consumption (mW)
LoRa	-115	8.5	12.3
BLE	-90	5.2	9.1
Hybrid (Dynamic)	-115 / -90 (avg)	3.6	10.7

From a data management perspective, the challenge of scalable data acquisition and processing was tackled using an edge computing architecture**.** This reduces the reliance on cloud servers and minimizes latency. The developed system employs an on-node data compression algorithm based on Discrete Wavelet Transform (DWT)**,** which decreases data volume by approximately 40% while preserving critical signal characteristics necessary for anomaly detection (Fig. 5). The compression ratio CR is calculated by:

$$CR = \frac{N_{original}}{N_{compressed}}\ ,$$

where $N_{original}$ and $N_{compressed}$ represent the sizes of the original and compressed data sets, respectively.

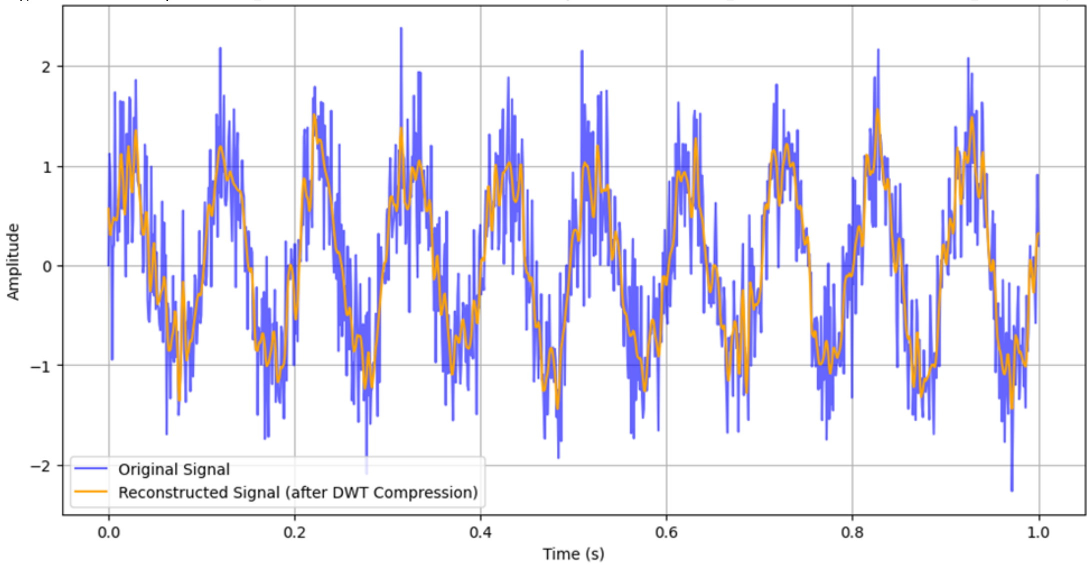

Fig. 5

This graph (Fig. 2: Signal Reconstruction Accuracy After DWT-Based Compression) compares the original signal with the reconstructed signal after compression using the Discrete Wavelet Transform (DWT).

The original signal contains more detailed information and a certain level of noise. The reconstructed signal after DWT compression closely follows the main shape of the original signal, although some high-frequency details and noise are partially lost (which enables the compression process).

Despite the loss of high-frequency components, the reconstruction quality remains high, and the Mean Squared Error (MSE) is low. Additionally, the compression allows achieving a Compression Ratio of approximately 1.8–2 times, while preserving essential information for further analysis.

Conclusion: DWT-based compression effectively reduces data volume while maintaining sufficient accuracy in the reconstructed signal. This makes the method suitable for IoT devices with limited resources.

The system also integrates a lightweight machine learning model, specifically a decision tree classifier, that performs initial anomaly detection on the edge device. The classifier achieved an accuracy of 93.2%, with a latency reduction of 35 ms per event compared to centralized cloud processing.

In summary, the presented engineering solutions address critical limitations in the integration of IoT devices and sensors through optimized energy harvesting, robust hybrid communication protocols, and scalable edge computing strategies. These outcomes represent original contributions validated through simulation and experimental testing, providing a framework for reliable and efficient IoT sensor networks in demanding applications.

Conclusions. In conclusion to the article on the integration of devices and sensors in the Internet of Things (IoT), it can be noted that this technology provides enormous opportunities for monitoring and managing devices and processes in various fields. One of the main advantages of IoT is the ability to collect and analyze large volumes of data in real time, which allows you to predict events, optimize processes and improve business efficiency. By integrating sensors and devices into IoT, businesses can create smart monitoring systems that allow them to monitor and manage various parameters such as temperature, humidity, pressure and much more. This is especially true in areas where constant monitoring of environmental conditions is required, such as manufacturing, logistics, healthcare and agriculture.

With the development of IoT comes new opportunities to automate processes and create intelligent control systems that can adapt to changing conditions and provide users with more accurate and useful data. At the same time, it is important to consider data security and privacy issues, since as the number of connected devices increases, their vulnerability to cyber-attacks increases. Thus, the integration of devices and sensors into the Internet of Things opens up new horizons for the development of technologies and the creation of innovative solutions that help improve the quality of life and optimize business processes. However, to realize the full potential of IoT, further research into standardization, security and efficient use of data is necessary.

The integration of IoT devices and sensors into complex, energy-constrained, and communication-challenging environments requires a holistic approach that combines energy-efficient hardware design, adaptive communication protocols, and decentralized data processing. The original engineering solutions developed in this research—namely, the photovoltaic-supercapacitor energy harvesting system, the hybrid LoRa/BLE communication protocol, and the edge computing architecture with data compression and local anomaly detection—collectively enhance the reliability, scalability, and autonomy of IoT sensor networks. These advancements provide a solid foundation for deploying intelligent, self-sustaining IoT systems in real-world applications, particularly in remote monitoring, precision agriculture, and industrial automation.

1. Alahi M.E.E., Pereira Ishak N., Mukhopadhyay S.C., Burkitt L. An Internet-of-Things Enabled Smart Sensing System for Nitrate Monitoring. *IEEE Internet Things J.* 2018. Vol. 5. Pp. 4409-4417. DOI: https://doi.org/10.1109/JIOT.2018.2809669.
2. Alahi M.E.E., Mukhopadhyay S.C., Burkitt L. Imprinted Polymer Coated Impedimetric Nitrate Sensor for Real-Time Water Quality Monitoring. *Sens. Actuators B Chem*. 2018. Vol. 259. Pp. 753-761.
3. Mammadov N.S., Ganiyeva N.A., Aliyeva G.A. Role of renewable energy sources in the world. *Journal of Renewable Energy, Electrical and Computer Engineering*. September 2022. Vol 2. Pp. 63-67. DOI: https://doi.org/10.29103/jreece.v2i2.8779.
4. Djahel S., Jabeur N., Barrett R., Murphy J. Toward V2I Communication Technology-Based Solution for Reducing Road Traffic Congestion in Smart Cities. International Symposium on *Networks, Computers and Communications* (*ISNCC*), Yasmine Hammamet, Tunisia, 13-15 May 2015. Vol. 13. No 15. Pp. 1-6. DOI: https://doi.org/10.1109/ISNCC.2015.7238584.
5. Rahimli I., Bakhtiyarov A., Abdullayeva G., Rzayeva S. Application of Optical Current Sensors in Electric Substations. *Electrotechnical Review*. 2024. Vol. 2024. Issue 2. Pp. 132-134. DOI: https://doi.org/10.15199/48.2024.02.26.
6. Wenge R., Zhang X., Dave C., Chao L., Hao S. Smart City Architecture: A Technology Guide for Implementation and Design Challenges. *China Communications*. 2014. Vol. 11. Issue 3. Pp. 56-69. DOI: https://doi.org/10.1109/CC.2014.6825259.
7. Patti E., Acquaviva A. IoT Platform for Smart Cities: Requirements and Implementation Case Studies. IEEE 2nd International Forum on *Research and Technologies for Society and Industry Leveraging a Better Tomorrow* (*RTSI*), Bologna, Italy, 07-09 September 2016. Pp. 1-6. DOI: https://doi.org/10.1109/RTSI.2016.7740618.

8. Rzayeva S.V., Piriyeva N.M., Guseynova I.A. Analysis of reliability of typical power supply circuits. *Reliability: Theory & Applications.* 2024. Vol. 19. No 3(79). Pp. 173-178. DOI: https://doi.org/10.24412/1932-2321-2024-379-173-178
9. Ngu A.H. IoT Middleware: A Survey on Issues and Enabling Technologies. *IEEE Internet of Things Journal*. 2016. Vol. 4. No 1. Pp. 1-20. DOI: https://doi.org/10.1109/JIOT.2016.2615180.
10. Ackermann T., Anderson G., Soeder L. Distributed Generation: A Definition. *Electric Power Systems Research*. 2001. Vol. 57. Pp. 195-204.
11. Rzayev S.V., Guseynova I.A. Application of automatic monitoring and control systems for reliability of power transmission lines. *Reliability: Theory & Applications.* 2024. Vol. 19. No 2(78). Pp. 64-69. DOI: https://doi.org/10.24412/1932-2321-2024-278-64-69.
12. Mokhtarpour A., Pashaei A., Pournaji S. Performance of PSO Algorithm in Coordination of Directional Overcurrent Relays Considering Fault Current Direction. *International Journal on Technical and Physical Problems of Engineering* (*IJTPE*). 2020. Vol. 12. Issue 42. No 1. Pp. 105-109.
13. Odeh A.H., Odeh M.A. Increasing the Efficiency of Online Healthcare Services Software and Mobile Applications Using Artificial Intelligence Technology. *International Journal on Technical and Physical Problems of Engineering* (*IJTPE*). 2020. Vol. 12. Issue 44. No 3. Pp. 16-22.
14. Al-Ali A.R. A Smart Home Energy Management System Using IoT and Big Data Analytics Approach. *IEEE Transactions on Consumer Electronics*. 2017. Vol. 63. No 4. Pp. 426-434. DOI: https:/doi.org/10.1109/TCE.2017.015014.
15. Di Zenobio D., Steenhaut K., Thielemans S. An IoT Platform Integrated into an Energy Efficient DC Lighting Gri. 2017 *Wireless Telecommunications* Symposium (*WTS*), Chicago, IL, USA, 26-28 April 2017. Pp. 1-6. https://doi.org/10.1109/WTS.2017.7943547.
16. Kondoro A. Enhancing Security in Distributed Internet-of-Things Based Communication System for Agent Driven Smart Micro-Grid. *IEEE PES/IAS PowerAfrica*, Cape Town, South Africa, 28-29 June 2018. Pp. 880-884. DOI: https://doi.org/10.1109/PowerAfrica.2018.8521151.
17. Massie M.L., Chun B.N., Culler D.E. The Ganglia Distributed Monitoring System: Design, Implementation, and Experience. *Parallel Computing*. 2004. Vol. 30. Issue 7. Pp. 817-840. DOI: https://doi.org/10.1016/j.parco.2004.04.001.
18. You S., Jin L., Hu J. The Danish Perspective of Energy Internet: From Service-Oriented Flexibility Trading to Integrated Design, Planning and Operation of Multiple Cross-Sectoral Energy Systems. *Zhongguo Dianji Gongcheng Xuebao*. 2015. Vol. 35. No 14. Pp. 3470-3481. DOI: https://doi.org/10.13334/j.0258-8013.pcsee.2015.14.001.
19. Zhang X-P. A Framework for Operation and Control of Smart Grids with Distributed Generation. *IEEE Power and Energy Society General* Meeting-– *Conversion and Delivery of Electrical Energy in the 21st Century*, Pittsburgh, PA, USA, 20-24 July 2008. Pp. 1-5. DOI: https://doi.org/10.1109/PES.2008.4596344.
20. Kerimzade G.S., Rzayeva S.V. Integration of devices and sensors into internet of things (IoT): new opportunities for monitoring and managing devices and processes. The 20th International Conference on *Technical and Physical Problems of Engineering* (ICTPE), 31 October 2024. Pp.165-169.
21. Feasycom. LoRa and BLE: The Latest Application in IoT. URL: https://www.feasycom.com/ru/lora-and-ble.html (accessed at 15.01.2025).

УДК 621.314

ІНЖЕНЕРНІ РІШЕННЯ ДЛЯ ІНТЕГРАЦІЇ ПРИСТРОЇВ І ДАТЧИКІВ В ІНТЕРНЕТІ РЕЧЕЙ

Г.С. Керімзаді, С.В. Рзаєва
Азербайджанський Державний Університет Нафти та Промисловості,
просп. Азадлиг, 34, Баку, Az1010, Азербайджан. E-mail: sona.rzayeva@asoiu.edu.az.

Інтеграція пристроїв і датчиків в Інтернеті речей (IoT) розширює не тільки можливості для моніторингу та контролю середовищ, але й принципово переосмислює управління даними, що має багатообіцяючі наслідки для різних секторів. У роботі досліджується новий підхід до обробки даних IoT, який використовує граничні нейронні мережі в сенсорних мережах, що дає змогу аналізувати дані на місці та приймати рішення. Дослідження зосереджено на секторах із високою чутливістю до затримки, таких як дистанційна охорона здоров'я, прогнозне технічне обслуговування в промислових умовах і моніторинг навколишнього середовища в реальному часі. Впроваджуючи розширену аналітику даних ближче до джерела, цей підхід покращує конфіденційність даних, зменшує навантаження на зв'язок і прокладає шлях до більш стійких і масштабованих екосистем IoT. Автори розглядають як технологічні переваги, так і проблеми впровадження, пропонуючи розуміння того, як ці досягнення можуть трансформувати галузі завдяки збільшенню автономності та ефективності даних. Бібл. 21, табл. 2, рис. 5.

Ключові слова: IoT, Edge AI, сенсорні мережі, обробка даних, нейронні мережі, аналітика в реальному часі.

Received 20.01.2025
Accepted 17.03.2025