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CHALLENGES, EMERGING TRENDS, AND FUTURE DEVELOPMENT OF REAL-TIME GIS

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ABSTRACT: *The paper examines the challenges, emerging trends, and future prospects for the development of real-time Geographic Information Systems (GIS). The first part analyzes the key challenges associated with the implementation and maintenance of such systems, including technical and infrastructural issues, data security and privacy, and the integration of heterogeneous data sources. The second part emphasizes future trends, such as the integration of artificial intelligence and machine learning, the advancement of 5G networks and the Internet of Things (IoT), cloud technologies, predictive analytics, as well as the expanded application of real-time GIS across various sectors, including healthcare, urban planning, energy, and agriculture. The main objective of the study is to outline the key directions for the development of real-time GIS and to highlight their importance for effective resource management, infrastructure oversight, and risk assessment in contemporary society.*

KEY WORDS: *Real-time GIS, Challenges, Artificial intelligence, 5G, IoT, Cloud technologies, Predictive analytics, Sustainable development, Cybersecurity.*

1. Introduction

Geographic Information Systems (GIS) are a key tool for collecting, processing, analyzing, and visualizing spatial data that support decision-making across various sectors of modern life - from disaster management and urban planning to transportation, healthcare, public safety, and environmental protection [1,2]. They enable mathematical calculations, logical expression evaluations, simulation of different scenarios, data sharing, and more. The broader concept of GIS technology integrates and organizes data of all types within a geographic framework.

The rapid advancement of the Internet of Things (IoT), 5G networks, and Artificial Intelligence (AI) in recent years has created new opportunities related to improved efficiency, cost reduction, and time savings. At the same time, it has introduced significant challenges concerning technical infrastructure, government policy, data security, and data quality [3]. It can be stated that the development of these technologies has transformed real-time GIS into a key factor for the sustainable development of modern societies [4].

The objectives of this paper are as follows:

- To analyze the key challenges in the implementation and use of real-time GIS;
- To outline the main trends and future perspectives for the development of such systems;
- To emphasize the importance of GIS as a strategic instrument for managing resources, infrastructure, and risks in both global and local contexts.

2. Exposition

Challenges in the Use of Real-Time GIS

The use of real-time Geographic Information Systems (GIS) represents a powerful tool for monitoring and analysis, increasingly applied in public safety, disaster management, the transportation sector, environmental monitoring, and other areas of critical infrastructure [1,2]. However, the integration and maintenance of real-time GIS are accompanied by a range of challenges arising from technical, organizational, and legal factors [3,5]. Some of the key challenges are outlined below (Figure 1).

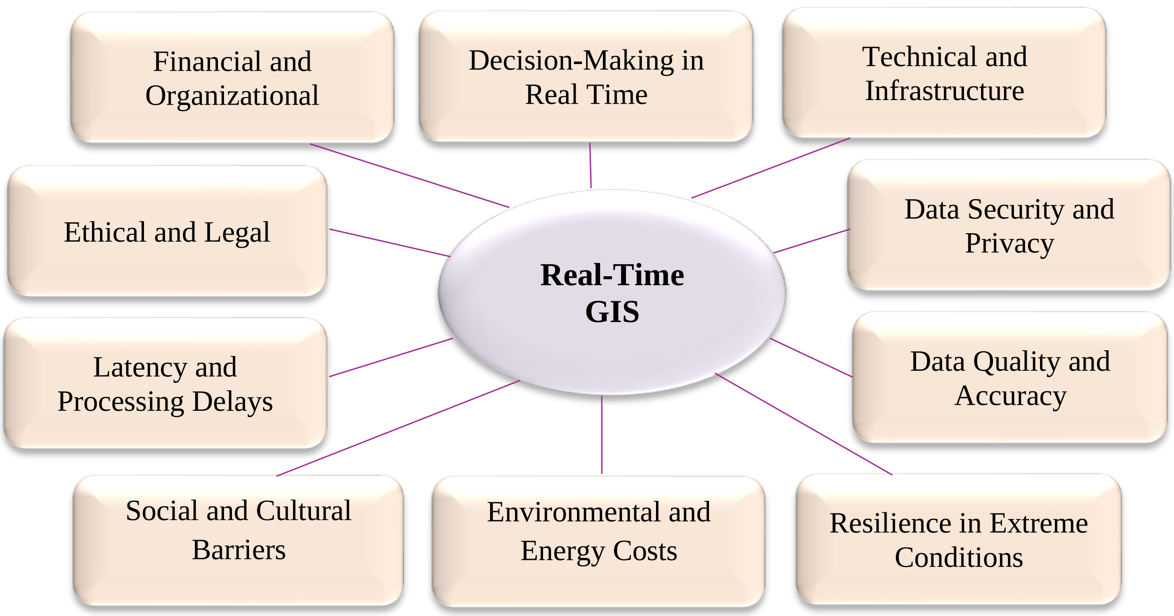


Fig. 1. Challenges of Real-Time GIS

Technical and Infrastructure Challenges.

The processing of large volumes of data is a crucial factor in the operation of real-time GIS systems. These systems require the handling of massive datasets generated from various sources - including sensors, IoT devices, drones, and satellites [3,4]. For the analysis to be effective, data must be collected, processed, and synchronized in real time. This places high demands on computational resources and network infrastructure.

Another important factor is the dependence on a stable network connection. To ensure the uninterrupted operation of real-time GIS, a reliable and high-speed network is essential, particularly when data are collected from remote or hard-to-reach areas. Interruptions or connection losses can cause system downtime or significantly reduce performance efficiency [6].

The limited capacity for data storage is also a major challenge. The processing of large datasets requires not only computational power but also substantial storage capacity. Long-term data retention and accessibility demand investments in cloud technologies and scalable server architectures. This, in turn, introduces specific requirements for data security and system reliability [7,8].

Standardization and data transformation represent another challenge, as real-time GIS must integrate information from multiple sources that often operate with different data formats and standards [3].

Data Security and Privacy.

Real-time GIS platforms process vast amounts of geospatial data, which often include personal information - such as the location of individuals and vehicles [5]. The collection and storage of such data require compliance with regulations such as the General Data Protection Regulation (GDPR). In this context, potential risks may arise concerning data protection and privacy, making it essential to establish strict data protection policies [9].

Cybersecurity is of critical importance for GIS platforms, especially those associated with national security and public services. The presence of sensitive data makes GIS systems potential targets for cyberattacks [7]. This necessitates the implementation of rigorous security measures, including data encryption, robust authentication protocols, access control mechanisms, and continuous system monitoring [8]. In addition, the presence of qualified and well-trained personnel is crucial to maintaining data security and preventing breaches.

Ensuring data security also involves the establishment of strict access control policies to manage permissions for both systems and specific datasets. This challenge is particularly evident in multi-user environments, where it is necessary to balance accessibility with the prevention of unauthorized access.

Alongside technical measures, ethical and legal aspects related to the collection and use of real-time data require special attention, as they directly affect public trust and the responsible use of spatial information [5,9].

Data Quality and Accuracy.

Real-time data may often be incomplete or contain errors. The cause can stem from technical issues such as malfunctioning sensors or poor network connectivity [4]. These problems frequently lead to inaccuracies in analysis and decision-making processes. As a result, data validation in real-time environments can be particularly challenging, as it requires the rapid detection and correction of errors.

Inaccuracies may also arise during the interpretation of information from different sources. Data obtained from various systems can differ in structure, and such inconsistencies may result in unreliable analytical outcomes [3]. For instance, sensor-generated data and satellite imagery may require different analytical and interpretation approaches [6,10]. Furthermore, outdated data pose an additional risk, as they can lead to incorrect conclusions and an incomplete assessment of potential hazards [2].

In order to enable a comprehensive assessment of the quality of research data, it is necessary to record or document specific information together with the data collected during the study. Such information is essential to ensure that data from different studies, conducted under varying requirements, can be effectively utilized [11].

Decision-Making in Real Time.

Insufficient time for analysis. In real-time situations, data are continuously collected and analyzed, which significantly reduces the time available for decision-making [4]. In certain cases, it becomes difficult to perform adequate analyses and forecasts on the spot, particularly in complex or rapidly evolving situations.

Process automation. In real-time GIS systems, automation is essential for processing large volumes of data. Building automated workflows capable of providing rapid and accurate results is technically challenging and often requires the integration of artificial intelligence (AI) and machine learning (ML) technologies [6,10]. However, incorrect data interpretation or errors within automated analyses can lead to faulty decisions. Such errors are difficult to detect and correct in real time, especially when the system heavily relies on automated processes.

Qualified personnel. The lack of specialists with expertise in real-time GIS operations remains a key obstacle to the effective use of these systems [1]. Insufficiently trained professionals may cause issues related to data quality, analytical precision, and overall system performance.

Financial and Organizational Challenges.

The development and maintenance of a real-time GIS system may require significant investments in systems, architectures, and resources - including hardware, software, network technologies, and personnel training [8,12,13]. This challenge is particularly relevant for small organizations or public institutions operating with limited budgets.

Another key issue is the lack of coordination and interoperability between different GIS platforms and technologies. In situations that demand rapid interaction - such as natural disasters or emergency events - the absence of system compatibility can hinder effective communication and coordination between agencies [9].

Moreover, GIS technologies and software evolve rapidly, which necessitates regular updates and continuous investment to maintain system relevance [7]. Organizations that fail to keep their GIS platforms up to date may encounter difficulties in utilizing new functionalities, ultimately reducing their operational efficiency and decision-making capabilities.

Ethical and Legal Challenges.

Compliance with legal regulations such as the General Data Protection Regulation (GDPR) is mandatory. Real-time GIS systems collect and process geolocation data that often fall under personal data protection laws. In this regard, organizations are required to implement strict data protection rules and policies, which can be resource-intensive and costly to maintain [9].

Ethical issues related to mass surveillance and large-scale data collection highlight the need for transparency and public debate [5]. The acquisition of real-time data from multiple sources may raise ethical concerns, particularly regarding the use of such information for continuous monitoring and tracking.

In many countries, legislation governing the use of GIS data remains underdeveloped, making it difficult for organizations to implement new practices and technologies. The absence of a unified legal framework may lead to ambiguity regarding the rights and responsibilities of stakeholders involved in data management and spatial analysis [2,9].

Resilience in Extreme Conditions. The GIS infrastructure must remain functional even during disasters and emergencies, when parts of the facilities or communication networks may be damaged or destroyed. The absence of backup systems and resilient architectures creates a significant operational risk [6,7]. This challenge is particularly critical for institutions responsible for managing and protecting critical infrastructure.

Latency and Processing Delays. Even with the availability of high-speed networks and powerful servers, delays in processing massive volumes of data are inevitable. In systems that require rapid response - such as traffic management or early warning systems - even a few seconds of delay can lead to incorrect or delayed decisions [4,6].

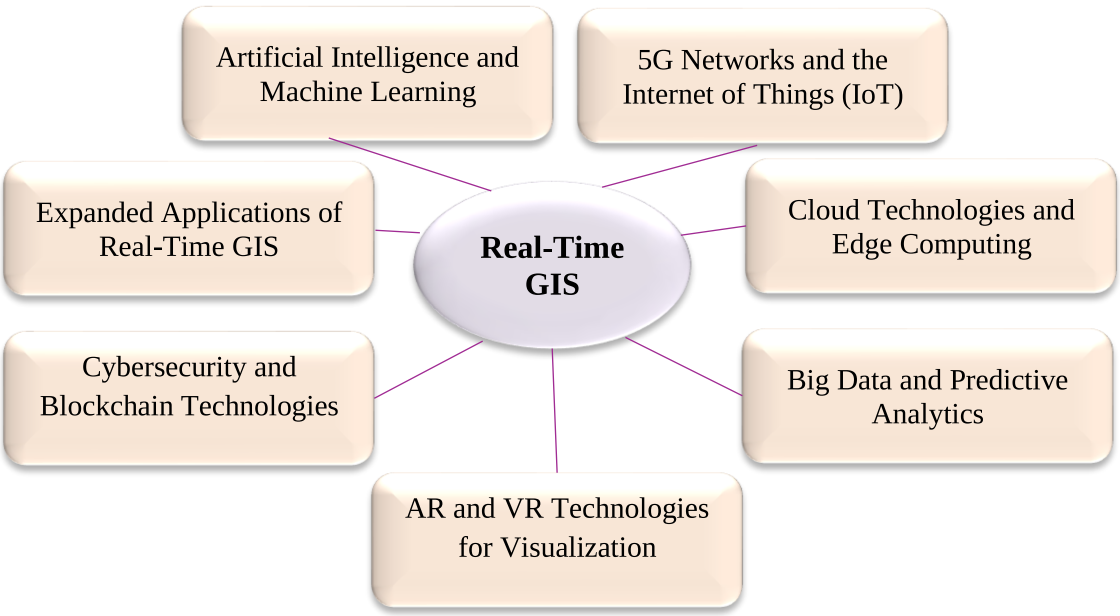
Social and Cultural Barriers. Even when secure and reliable technologies are available, organizations and society are not always ready to adopt them. A lack of trust in data accuracy, reluctance to share information, and insufficient staff training are factors that limit the effective use of these technologies [1,9].

Environmental and Energy Costs. Real-time GIS systems require the continuous operation of servers, data centers, and sensor networks. This results in significant energy consumption and raises important questions about the sustainability of the technologies themselves [2,13]. The development of energy-efficient algorithms and green data centers has therefore become essential.

In summary, although real-time GIS offers enormous potential for improving efficiency and security, its implementation is associated with substantial challenges. These challenges encompass not only technical and organizational dimensions but also issues of interoperability, disaster resilience, social acceptance, and environmental sustainability. Overcoming them requires joint efforts from technical teams, government institutions, the private sector, and society as a whole [1,5,8,9].

Future Trends and Development of Real-Time GIS

In recent years, the development of real-time Geographic Information Systems (GIS) has emerged as a key driver of digital transformation across various sectors of society. While traditional GIS platforms have primarily focused on the analysis and visualization of retrospective data, modern trends emphasize the immediate collection, processing, and presentation of information [5]. This shift enables rapid responses to dynamically changing conditions and provides stakeholders with new tools for informed decision-making. Figure 2 summarizes the seven major trends in the evolution of real-time GIS.



Фиг. 3. Future Trends in Real-Time GIS

Several major trends define the evolution of real-time GIS:

- Artificial Intelligence and Machine Learning.

The integration of Artificial Intelligence (AI) and Machine Learning (ML) into GIS has become one of the leading trends in recent years [4]. AI enables the automatic detection of spatial patterns and correlations while reducing the risk of human error. By analyzing large volumes of real-time data, GIS systems can predict the occurrence of specific events - such as floods, wildfires, environmental hazards, or traffic congestion [6]. Machine learning also supports the automation of processes that traditionally required manual input, including satellite image processing, sensor data validation, and transportation route optimization.

In the context of smart cities, AI facilitates adaptive traffic management, intelligent resource allocation, and infrastructure load forecasting, helping communities become safer, more livable, well-managed, prosperous, and sustainable. This transforms real-time GIS into a strategic tool for enhancing the efficiency and resilience of urban environments.

- Development of 5G Networks and the Internet of Things (IoT).

High-speed 5G networks with low latency make it possible to continuously collect information from millions of connected devices. The Internet of Things (IoT) already provides an unprecedented amount of data from diverse sources - from air and soil quality sensors to smart traffic cameras and autonomous drones [9].

In real time, these data streams can be integrated into GIS platforms to support decision-making across multiple sectors. In agriculture, IoT combined with GIS enables precise monitoring of crop conditions and optimization of water and fertilizer use. In the energy sector, sensors monitor network conditions and report faults, reducing response times. In healthcare, IoT devices can provide population mobility and disease spread data, which is particularly valuable during pandemics.

- Cloud Technologies and Edge Computing.

With the increasing volume of spatial data, efficient storage and processing have become essential. Cloud platforms provide flexibility, scalability, and accessibility, allowing GIS to be deployed even by organizations with limited resources [7].

In combination with edge computing, a balance is achieved between centralized and decentralized processing. Data can be preprocessed near their source - for example, by sensor devices or local stations - before being transmitted to the cloud. This reduces latency, which is particularly important in critical situations such as disaster management or traffic control.

- Integration with Big Data and Predictive Analytics.

Modern GIS platforms can integrate with Big Data systems, enabling complex analyses that include both spatial and temporal relationships [3]. Access to large volumes of real-time data is extremely valuable for managing various sectors.

Predictive analytics based on GIS is increasingly used to forecast climate change impacts, assess natural disaster risks, and even support market and economic strategies. Real-time data processing allows the creation of dynamic models that facilitate timely and well-informed decision-making.

- AR and VR Technologies for Visualization.

Augmented Reality (AR) and Virtual Reality (VR) technologies are gaining wider use in GIS, offering a new level of visualization in which spatial data can be directly integrated into the real environment [8]. Examples include visualizing future buildings on real terrain through AR for urban planning, or training emergency response teams through VR simulations. These technologies transform GIS from an analytical tool into an interactive platform for planning, education, and management.

- Cybersecurity and Blockchain Technologies.

As GIS becomes increasingly important for managing critical infrastructure, data security has become a central concern [2,9]. Advanced cybersecurity mechanisms will continue to be integrated into GIS platforms to protect sensitive information.

Blockchain technology offers a potential solution for ensuring data immutability and authenticity. This is particularly valuable for inter-institutional and international cooperation, where trust in data sources is of critical importance.

- Expanded Applications of Real-Time GIS.

A growing trend is the expanded application of real-time GIS in various sectors of society and the economy [2,9]. Examples include:

- Healthcare – monitoring health risks, tracking disease spread, and optimizing medical resources;
- Urban Planning – monitoring traffic flows and managing infrastructure;
- Energy – managing power grids and predicting failures;
- Agriculture – optimizing production processes and promoting sustainable resource use, including land management;
- Environment – monitoring pollution and managing natural resources;
- Public Administration – waste management, service provision, urban planning, and demographic analysis;
- Security – disaster response coordination and public safety management.

These examples demonstrate that real-time GIS is evolving into a universal instrument for managing complex systems and supporting evidence-based decision-making in diverse domains.

3. Conclusion

Real-time Geographic Information Systems have established themselves as a critically important technological platform for the modern world. They not only provide immediate access to spatial information but also create the foundation for integrated solutions encompassing infrastructure, healthcare, transportation, energy, environmental protection, and other key sectors [1, 8].

The challenges related to security, data quality, organizational capacity, and financial sustainability remain significant and require a systematic approach. Addressing these issues can be achieved through sound government policy, investment in infrastructure, the enhancement of standards, and intersectoral cooperation. At the same time, emerging technologies offer substantial new opportunities.

Real-time GIS is becoming a strategic instrument for sustainable development and disaster management, supporting timely decision-making, reducing the risk of human error, and increasing the efficiency of public and private institutions. It serves as a foundation for innovative policies, improved resource management, and the creation of „smart" and resilient societies.

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