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Review of big data visualization technology with artificial intelligence

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Abstract. In the digital age, where the amount of data is growing exponentially, traditional big data visualization methods often fall short, especially when it comes to processing high-dimensional data or matching visualization results to user needs. This highlights the need for better integration between Artificial Intelligence (AI) and big data visualization. AI has brought about significant changes in this field. This paper reviews research from the past five years to explore the integration of AI with big data visualization. It looks at the core technologies, common use cases, and challenges of this combination. The review finds that AI can address many issues in traditional visualization techniques, such as handling complex data and improving interaction and evaluation. However, challenges like model interpretability, data privacy concerns, and inconsistent standards remain. In the future, this integration is expected to move toward more transparent models, stronger privacy protection, and standardized systems. This will help unlock the full value of data in real-world applications.

Keywords: big data visualization, literature review, technology integration, data-driven decision-making

1. Introduction

With the continuous advancement of information technology and digital transformation, the scale and types of data are experiencing a sustained growth trend. Large-scale, multi-source, and heterogeneous data have become a common challenge faced by various fields [1]. In this context, how to effectively understand, analyze, and utilize data has become a key element in data-driven decision-making [2]. The rapid growth of big data has not only brought enormous opportunities but also unprecedented challenges. Traditional data analysis methods are often limited by the scale of data, data types, and processing time, thus creating an urgent need for more efficient and automated analytical approaches.

Big data visualization, as an important means of bridging data analysis and human cognition, helps users identify patterns, trends, and anomalies in the data by transforming abstract data into intuitive visual representations. However, traditional visualization methods often rely on manual rules and predefined models, which struggle to balance analytical efficiency and cognitive load when dealing with high-dimensional, dynamic, and complex data [3]. In this regard, the introduction of artificial intelligence undoubtedly provides a new breakthrough for visualization technology. The intelligent characteristics of AI enable it to process complex data more accurately, not only enhancing the depth of analysis but also expanding the breadth of data visualization.

Relevant studies suggest that artificial intelligence has advantages in feature learning, pattern recognition, and data modeling, and can partially compensate for the limitations of traditional visualization techniques in automation and adaptability [2]. The introduction of artificial intelligence has transformed visualization from being just a static display tool into a core component of dynamic data analysis and decision support.

This paper focuses on the integration of artificial intelligence and big data visualization technologies, with particular attention to the application forms and technical approaches of artificial intelligence in big data visualization systems. By systematically reviewing relevant studies published in recent years, the paper analyzes and summarizes AI-enabled big data visualization research from the perspectives of technical foundations, methodological frameworks, and application contexts. Through this process, the study seeks to develop an overall understanding of the current research landscape in this field, thereby enabling a clearer interpretation of how different technological approaches function within visualization systems. On this basis, the paper aims to provide reference insights for subsequent research and offer theoretical support for the rational design and practical implementation of artificial intelligence and big data visualization technologies in specific application scenarios.

2. Big data visualization technology theory

Big data visualization refers to the technique of transforming complex data into intuitive information through graphical and interactive methods, thereby supporting users in data analysis and cognitive understanding. Its core objective is not merely to display data, but to assist users in identifying structural relationships, trends, and potential issues within the data through visual representation [1]. In this process, the "visibility" and "interpretability" of data are two key elements. The success of visualization technology depends on how effectively it can not only present the data but also help users better understand the underlying logic behind the data.

As the scale of data continues to expand and the structure of data becomes increasingly complex, traditional visualization methods gradually show limitations in terms of adaptability.These methods typically rely on manually set visual mapping rules, and when the data has high dimensions or comes from diverse sources, users need to invest a high cognitive cost to complete the analysis tasks [3]. This is one of the reasons why artificial intelligence has quickly integrated into this field. Through adaptive learning, AI technology can effectively reduce the cognitive burden on users during data processing and analysis, thereby enhancing the overall intelligence of the system.

To address the above issues, researchers have begun to integrate artificial intelligence technology into the field of big data visualization to enhance the system's automation and intelligence levels. From a system structure perspective, big data visualization typically involves stages such as data collection, data preprocessing, analytical modeling, and visual presentation.In the data collection and preprocessing stages, artificial intelligence can assist in anomaly detection and feature selection, improving data quality [4]. This not only improves the efficiency of data processing but also ensures the quality and accuracy of data during the visualization process, further enhancing the reliability and application value of the data.

In the analysis modeling stage, visualization systems based on intelligent analysis models can automatically discover hidden patterns in the data, providing users with more valuable information structures.Compared to traditional statistical analysis methods, these systems offer better flexibility when handling complex relationships between data [1]. Visualization technology can better meet the demands of high-complexity data analysis thanks to artificial intelligence, which not only streamlines data processing but also offers a deeper comprehension and disclosure of the links underlying the data.

From an overall design perspective, the degree of collaboration between artificial intelligence and visualization significantly impacts user experience and analysis effectiveness. If there is a lack of effective integration between the analysis model and the visualization interface, even if the model itself has high analytical accuracy, its results may be difficult for users to fully understand and utilize. In AI-enabled big data visualization systems, both technical performance and interactive design should be regarded as equally important components. This collaborative relationship indicates that big data visualization is not just about presenting results but is also an integral part of the analytical process. Its success depends not only on the precision of the technology but also on good user experience design.

3. Artificial intelligence-enabled big data visualization technologies

AI-enabled big data visualization technology primarily focuses on the collaborative enhancement of data analysis capabilities and visual representation abilities.n this process, visualization gradually evolves from a tool for presenting results to an integral part of the analytical process [2]. Future visualization systems will not only serve as a medium for data display but will also form a complete feedback loop of "intelligent analysis—result presentation".

3.1. Healthcare applications

In the healthcare sector, big data visualization provides an effective means of integrating complex medical data. Relevant studies suggest that visualization systems combined with intelligent analysis models help healthcare professionals understand patient data characteristics and improve the efficiency of auxiliary analysis [5]. By intelligently visualizing diagnostic data, imaging data, and real-time monitoring data, doctors can more comprehensively assess a patient's health status and offer personalized treatment plans. This provides technological support for the development of precision medicine and personalized healthcare.

3.2. Financial and economic analysis

In the financial sector, analyzing complex financial data and presenting it through visualization can provide valuable insights for investment decision-making [6]. The rapid changes in financial markets require decision-makers to monitor market conditions in real-time and respond promptly. AI-driven visualization technology offers financial analysts more efficient and intuitive decision-support tools, particularly demonstrating immense potential in high-frequency trading and market forecasting.

3.3. Smart city and urban governance

In the field of smart cities, large amounts of traffic, population, and infrastructure data provide the foundation for visual analysis. Studies show that presenting intelligent analysis results through visualization helps urban managers understand the operating status of cities and supports planning decisions [7, 8]. This approach not only displays static information but also highlights dynamic changes, enabling decision-makers to make more precise judgments in a constantly changing environment. This multi-dimensional, multi-level visualization greatly enhances the flexibility and responsiveness of urban management.

3.4. AI-enabled traffic management and real-time flow prediction

In traffic management scenarios, AI-enabled visualization systems can dynamically display traffic operations, thereby supporting scheduling and management [4]. This big data-based traffic flow prediction and real-time monitoring make traffic management more efficient and intelligent. Especially during peak traffic periods and in emergency management, the combination of AI and visualization can provide strong decision support, significantly enhancing the responsiveness and accuracy of traffic management systems.

A comparison of research across different application domains reveals that AI-enabled big data visualization does not follow a uniform implementation model. Smart cities and traffic management focus more on the system's real-time capabilities and overall situational awareness, while healthcare and finance place greater emphasis on the accuracy and interpretability of analysis results. This indicates that in specific applications, intelligent visualization systems often need to balance analytical depth, interaction complexity, and system stability, with this balance closely related to actual usage needs. Future research should focus more on customizing visualization solutions based on the specific requirements of different fields, rather than adopting a one-size-fits-all approach.

4. Challenges of AI-enabled big data visualization

Although AI-enabled big data visualization technology has demonstrated its application potential across various fields, existing studies generally agree that the technology still faces multiple challenges in practical implementation.These difficulties are intimately linked to the application environment and data characteristics in addition to technological implementation.

A significant issue is the lack of model interpretability. Some studies point out that intelligent analysis models lack clear explanations of the analysis process when generating visualization results, which in turn affects users' understanding and trust in the system's results.This problem is particularly critical in high-risk areas such as healthcare and finance, where the transparency and interpretability of data directly impact the users' reliance on the analysis results. Designing more transparent and interpretable analysis models is a key issue that needs to be addressed in the field of big data visualization.

In addition to issues related to model interpretability and data security, practical deployment challenges also constrain the application of AI-enabled big data visualization systems. In real-world environments, balancing data timeliness with computational resource requirements remains a persistent technical difficulty. In smart city scenarios, although data sources are abundant and real-time processing demands are high, the computational cost of large-scale data processing and visualization may introduce system latency, which can negatively affect decision-making efficiency. Addressing these challenges requires not only advances in algorithms and hardware infrastructure but also optimization strategies tailored to specific industry contexts. Moreover, as AI technologies continue to be widely adopted, concerns related to ethical compliance and fairness in application are becoming increasingly prominent. Under these circumstances, the establishment of industry standards and the enhancement of model interpretability are essential for supporting the stable and sustainable development of AI-enabled big data visualization technologies.

Data security and privacy protection are also widely concerned. Large volumes of sensitive data must frequently be processed by AI-driven data analysis systems, and data breaches are possible in the absence of efficient security management solutions [5, 9].

Existing research indicates that some AI-enabled big data visualization systems have not been sufficiently discussed in terms of their long-term operation in real-world environments. During actual deployment, factors such as changes in data scale, variations in user behavior, and system maintenance costs can affect system performance. Therefore, it is necessary to differentiate between experimental validation results and real-world performance when evaluating related research outcomes. For emerging fields, particularly those involving complex systems and large-scale datasets, ensuring sustainability and scalability will be a key focus of future research.

5. Future trends in AI-enabled big data visualization

The integration of artificial intelligence with big data visualization is not only changing the way data is analyzed but is also shaping decision-making processes across various fields. Looking to the future, several emerging trends will further refine and redefine the role of AI in big data visualization.

Advancements in machine learning and deep learning algorithms have enhanced the predictive capabilities of big data visualization systems. By continuously learning from new data, AI models can provide more accurate predictions, helping businesses and organizations make timely and informed decisions. In fields such as finance and healthcare, decisions are highly time-sensitive and rely heavily on data [6, 9].

The rise of edge computing will influence the deployment of AI-driven data visualization systems. Edge computing allows for local data processing, which removes the need to send massive volumes of data to centralized servers for real-time visualization due to the growing volume of data created at the network edge, such as Internet of Things (IoT) devices. This reduces latency, improving the efficiency of AI-driven visualization systems in fields like autonomous driving, smart cities, and industrial automation [3, 7].

AI's role in improving Human-Computer Interaction (HCI) is continually increasing. AI systems are gradually improving their understanding of human behavior and preferences, making data visualization interfaces more intuitive and customizable. Users can interact with visualization systems in a more personalized way, enhancing their ability to extract insights from complex datasets [5].

As data privacy and ethical concerns grow, the future will see a greater emphasis on developing efficient, transparent, interpretable, and fair AI models. With the increasing adoption of AI-driven data visualization technologies, it is essential to ensure these systems are ethical and secure [10]. Consequently, new frameworks for data governance and privacy protection will ensure AI systems comply with regulatory standards while providing valuable insights [6].

The integration of AI with big data visualization is rapidly advancing and will bring many exciting technological advancements in the future. As AI continues to evolve, it will not only help organizations unlock the full potential of their data but also create more intelligent and efficient systems across multiple industries [9].

6. Conclusion

Based on relevant research findings, this paper provides a systematic review of AI-enabled big data visualization technologies. From both theoretical and practical perspectives, the introduction of AI technology helps improve the analytical capabilities of visualization systems in complex data environments. Innovations in data processing, analysis, and presentation enabled by artificial intelligence allow visualization technologies to better meet the evolving demands of various applications and demonstrate strong potential value across multiple fields.

AI-enabled big data visualization has made significant exploratory progress in areas such as smart cities, traffic management, healthcare, and finance. These applications showcase the potential value of intelligent visualization in assisting analysis and supporting decision-making, although their effectiveness still depends on specific application scenarios and system designs.

Based on the analysis, it can be concluded that AI-enabled big data visualization technologies are currently more suitable as tools for supporting data analysis and decision-making rather than fully automated decision systems. Future research should focus on improving the intelligence level of these systems while also addressing the rational design of human-machine collaboration. This should be done while ensuring data security and interpretability, and promoting the steady application of these technologies in real-world scenarios.

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