

REVIEW

Open Access



Edge intelligence-assisted animation design with large models: a survey

Jing Zhu¹, Chuanjiang Hu², Edris Khezri^{3*} and Mohd Mustafa Mohd Ghazali¹

Abstract

The integration of edge intelligence (EI) in animation design, particularly when dealing with large models, represents a significant advancement in the field of computer graphics and animation. This survey aims to provide a comprehensive overview of the current state and future prospects of EI-assisted animation design, focusing on the challenges and opportunities presented by large model implementations. Edge intelligence, characterized by its decentralized processing and real-time data analysis capabilities, offers a transformative approach to handling the computational and data-intensive demands of modern animation. This paper explores various aspects of EI in animation and then delves into the specifics of large models in animation, examining their evolution, current trends, and the inherent challenges in their implementation. Finally, the paper addresses the challenges and solutions in integrating EI with large models in animation, proposing future research directions. This survey serves as a valuable resource for researchers, animators, and technologists, offering insights into the potential of EI in revolutionizing animation design and opening new avenues for creative and efficient animation production.

Keywords Edge computing, Animation design, Large model, Intelligent computing, Survey

Introduction

The integration of edge intelligence in animation design, particularly with large models, represents a significant shift in the animation and computing industries. Edge computing, a distributed computing paradigm that brings computation and data storage closer to the location where it is needed, enhances the efficiency and speed of data processing, especially for resource-intensive tasks like animation design [1]. The advent of large models in animation has revolutionized the way animators and designers approach their craft, offering unprecedented levels of detail and realism [2]. However, these models

require substantial computational resources, often necessitating the use of cloud computing infrastructures which can introduce latency and bandwidth issues. Edge intelligence emerges as a solution, combining the power of edge computing with advanced analytics and machine learning to optimize animation processes [3], which is exemplified in Fig. 1.

This survey aims to explore the current state of edge intelligence-assisted animation design, focusing on the use of large models. The primary objectives are to understand how edge intelligence is being integrated into animation design, identify the benefits and challenges of this integration, and highlight the latest advancements and applications in the field. The scope of this survey encompasses a review of existing literature and case studies that illustrate the practical applications of edge intelligence in animation, with a particular emphasis on large model utilization.

The reminder of this paper is organized as follows. In "Fundamentals of Edge Intelligence" section, we introduce the fundamental knowledge of edge computing as

*Correspondence:

Edris Khezri
edris.khezri@qiau.ac.ir

¹ Faculty of Creative Industries, City University Malaysia, Petaling Jaya, Malaysia

² Anhui Vocational and Technical College of Industry and Trade, Huainan, China

³ Department of Computer Engineering, Boukan Branch, Islamic Azad University, Tehran, Iran

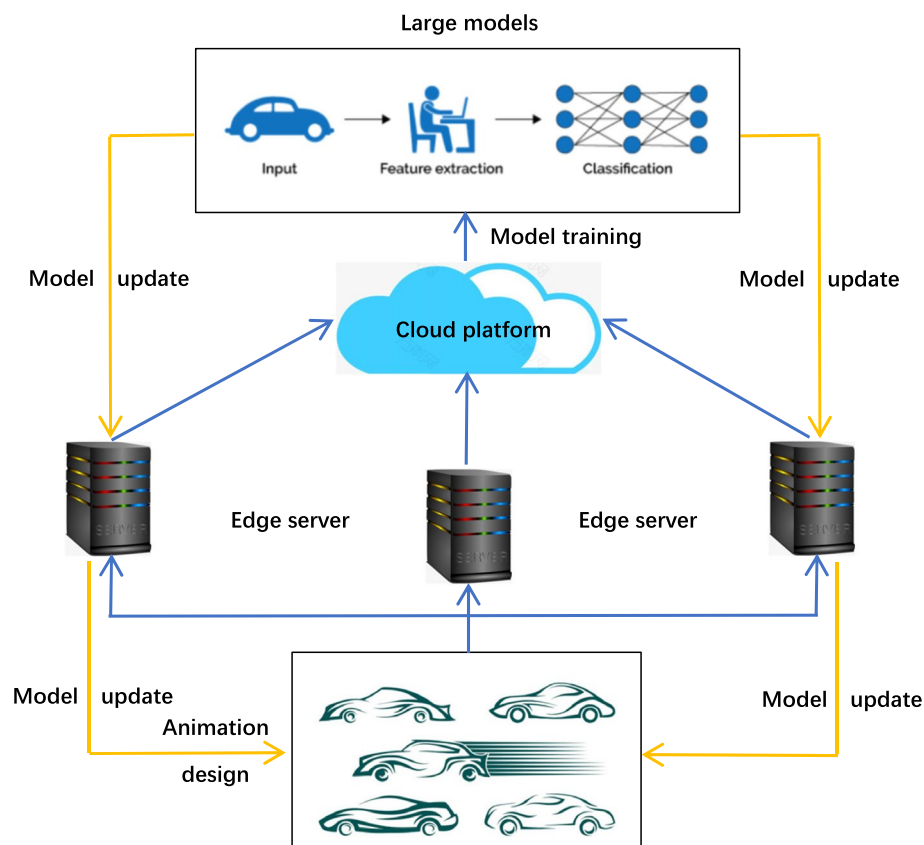


Fig. 1 Edge intelligence-aided animation design with large models: an example (blue lines denote data collection and processing while yellow lines denote model update and feedbacks)

well as edge Intelligence. In "[Large Models in Animation Design](#)" section, the research progress of large models in animation design is investigated. We review the current status of integration of edge intelligence in animation design in "[Integration of Edge Intelligence in Animation Design](#)" section. Technical aspects of edge-assisted animation design are presented in "[The Need for Edge Intelligence in Animation](#)" section. Finally, we conclude the whole paper and point out the future research topics in "[Case Studies: Successful Implementations](#)" section.

Fundamentals of edge intelligence

Edge computing represents a paradigm shift in data processing, where computation is performed at or near the data source, rather than relying solely on centralized cloud-based systems [4–6]. This approach significantly reduces latency, a critical factor in real-time applications such as animation design [7] describes edge computing as a method to circumvent the latency issues inherent in cloud computing, making it particularly suitable for time-sensitive applications. By processing data locally, edge computing also reduces bandwidth usage, which is essential for handling large models in animation. The

concept of edge computing emerged as a response to the exponential growth of IoT devices and the need for faster processing and decision-making at the data source [1]. Furthermore, edge computing facilitates a more scalable and efficient approach to data management, as outlined by [8], who emphasize its role in managing the data deluge from IoT devices. Recent advancements in edge computing, such as those discussed by [9], have further demonstrated its potential in smart city applications, including video analytics, by leveraging distributed systems and machine learning tasks.

Edge intelligence is the natural progression of edge computing, integrating artificial intelligence (AI) into the edge of the network. This integration allows for more sophisticated data processing and analytics, enabling real-time, intelligent decisionmaking. For example, [3] discusses how edge intelligence represents the convergence of AI and IoT, where devices not only collect data but also analyze and act upon it intelligently. The evolution of edge intelligence is marked by this convergence, leading to decentralized processing, reduced latency, and context-aware computing, all of which are crucial for the dynamic and resource-intensive field of animation

design. Chen et al. [10] further elaborates on the principles of edge intelligence, highlighting its potential to transform various industries by bringing AI capabilities closer to the data source. Bellavista et al. [11] provides a practical example of machine learning for predictive diagnostics at the edge in an Industrial Internet of Things (IIoT) environment, showcasing the application of edge intelligence in real-world scenarios.

Several key technologies underpin edge intelligence, including distributed data processing, machine learning, and real-time analytics. Distributed data processing allows for handling large volumes of data generated by animation processes, while machine learning algorithms enable the system to learn and improve over time. Abbas et al. [12] discusses the role of machine learning in enhancing the capabilities of edge computing systems, particularly in terms of data analytics and decision-making. Real-time analytics are essential for providing immediate feedback and adjustments in animation design. The architectures of edge intelligence systems are typically layered, comprising the edge layer (where data is generated and initially processed), the fog layer (which provides additional processing and storage capabilities), and the cloud layer (for more extensive processing and long-term storage). Bonomi et al. [13] describes this layered architecture, emphasizing its role in facilitating a more efficient and scalable approach to handling complex data sets, such as those found in animation. Recent studies like that of [14] has explored the integration of deep neural networks in cloud-edge collaboration schemes, highlighting the advancements in edge intelligence for real-time data analytics in IoT-based systems.

Large models in animation design

Large models in animation design, driven by AI and machine learning, have revolutionized the field, enabling high-fidelity, realistic animations. Capobianco et al. [15] discusses the transformative role of intelligent systems in various domains, including animation. Although its primary focus isn't animation, it provides valuable insights into how intelligent systems can be transformative in various fields, including animation. It discusses how high-dimensional data analysis, made possible by AI and machine learning, is crucial in complex fields like cancer research. It delves into the aspects of data handling, processing, and interpretation in high-stakes scenarios, providing parallels to the complexities faced in animation design. Khuat et al. [16] highlights the growing adoption of machine learning-based models in animation due to large-scale data. Although this study primarily focuses on biopharmaceutical processes, it underscores the growing adoption and importance of machine learning models in diverse sectors. It highlights how machine learning,

through the analysis of large-scale data, can drive innovation and efficiency in various fields such as animation design. This paper explores specific machine learning techniques and trends, which are also relevant to animation design, such as deep learning, neural networks, and the handling of complex datasets. Additionally, [17] explores the use of the optimized AVOD algorithm for animation design, enhancing the efficiency and accuracy of animation creation. This research directly addresses animation design, focusing on the use of the optimized Aggregate View Object Detection (AVOD) algorithm. It explores how multi-sensor data fusion can be leveraged in animation, enhancing the efficiency and accuracy of animation creation. The paper details the technical aspects of the AVOD algorithm, its optimization process, and its application in creating more realistic and high-fidelity animations.

The evolution of animation design models reflects rapid technological development. For example, [18] explores AI and machine learning integration with digital twinning in animation design; This paper provides a systematic review of AI, machine learning, and big data in digital twinning, which is highly relevant to animation design. It discusses the integration of these technologies in creating digital twins, a concept that can be applied to creating realistic and dynamic animation models. The authors also outline the challenges and opportunities in this field, offering insights into how digital twinning can revolutionize animation design. Soelistiono et al. [19] reviews challenges in training large machine learning models in animation studios; This survey focuses on the acceleration of training large machine learning models, particularly in the context of the Internet of Things (IoT), which has implications for animation studios. It reviews the challenges faced in training large models and suggests solutions, which can be beneficial for animation studios dealing with complex animations and simulations. In addition, the paper also discusses techniques and tools that can optimize the training process, thus aiding in more efficient animation production [20] discusses the AI-Integrated Learning System Design in AILS-Based Education, highlighting its application in 3D animation. This paper explores the design of AI-Integrated Learning Systems (AILS) in education, with a focus on its application in 3D animation. It contributes insights into how AI can enhance educational technology, particularly in teaching and learning 3D animation skills and also provides examples or case studies of AILS in action, demonstrating its effectiveness in enhancing the learning experience in animation education. Similarly, [21] delves into the virtual experiment teaching system, emphasizing the role of virtual reality technology in animation. Although focused on a virtual experiment

teaching system for a transplanting machine, this paper sheds light on the use of virtual reality technology in educational systems. It underscores the role of virtual reality in creating immersive and interactive environments, which is directly applicable to animation. The study also details the system's design and implementation, providing a blueprint for how similar technologies can be used in animation design. While [22] explores fog computing as a solution for data management in animation, especially in handling the vast amount of data generated in animation studios. Additional references for this section include the works of [23] on AI-assisted animation game development.

Integration of edge intelligence in animation design

The need for edge intelligence in animation

Edge intelligence is becoming increasingly important in animation design due to its ability to process large amounts of data efficiently and in real-time. This is crucial in animation, where rendering and processing tasks are data-intensive and time-sensitive. The integration of edge computing in animation allows for faster processing times and more efficient data handling, which is essential in creating high-quality animations.

The paper [24] focuses on the real-time interaction and control access technology of communication information of Power IoT Gateway based on edge intelligence technology. It emphasizes the importance of edge intelligence in managing complex data flows and real-time processing, which is crucial in animation for handling large datasets and ensuring timely rendering. The study provides insights into how edge intelligence can enhance the efficiency of data processing and communication, which can be directly applied to animation design for improved performance and real-time interaction. In work [25], the authors investigate the design and algorithms of a real-time image edge detection system using artificial intelligence and FPGAs. It highlights the importance of high-speed processing and real-time data handling, which are essential in animation for tasks like rendering and image processing. This paper demonstrates the application of FPGA technology in image data processing, providing a model for animation design where real-time processing and high data throughput are critical.

Work [26] focuses on real-time intelligent image processing for the Internet of Things, exploring the application of edge intelligence in managing and processing image data efficiently. The proposal in the paper is relevant to animation as it provides insights into how edge intelligence can be utilized for efficient image processing, a key aspect in animation design, especially in scenarios involving large volumes of data. The authors in [27]

present a TinyMLaaS (Tiny Machine Learning as a Service) architecture for IoT deployments, focusing on executing ML models on low-power embedded devices. It addresses design trade-offs in energy consumption, security, privacy, and latency. The TMLaaS architecture is significant for animation, offering a framework for efficient, secure, and low-latency edge intelligence applications, crucial for real-time animation processing and rendering.

The authors surveys recent advances in the efficient processing of deep neural networks (DNNs) at the edge, focusing on hardware-aware deployment and low-complexity on-chip training [28]. The insights into hardware-aware DNN deployment are vital for animation, as they provide guidelines for optimizing edge intelligence implementations in resource-constrained environments, enhancing the performance of animation applications. In [29], the comprehensive study of edge intelligence discusses its key concepts, advantages, development trends, and collaboration modes, focusing on model training and inference processes. The framework and insights provided in this study are crucial for animation, offering a broad perspective on how EI can be effectively implemented and utilized in animation design and rendering processes. In [30], the paper discusses the convergence of edge intelligence with the infrastructure layer of the Metaverse, focusing on the stringent requirements of sensing, communication, and computation. The exploration of edge intelligence in the context of the Metaverse provides valuable insights for animation, particularly in terms of developing immersive and interactive virtual environments, which are increasingly relevant in animation and gaming industries.

Case studies: successful implementations

The authors in [31] developed a UAV system capable of performing multiple road infrastructure monitoring tasks in real-time. The system's design and performance, particularly in computational strain and latency, are discussed. This case study is relevant for animation as it demonstrates the efficiency of edge computing in processing complex, real-time data. In [32], the authors compare traditional and AI-integrated design education methods. It highlights how AI technology, when applied to animation design education, can enhance design vision, teaching methods, and productivity. This case study shows the potential of AI and edge intelligence in revolutionizing animation design education. Work [33] assesses a house for green building optimization and energy efficiency using EDGE software. The comparative analysis of different rating systems provides insights into the application of edge intelligence in sustainable design, which can be applied to animation design for eco-friendly practices. While literature [34] evaluates the design of

campus buildings in terms of thermal and energy performance. The study's comparative analysis using EDGE building software offers valuable insights into energy-efficient design, which is applicable in animation studios for sustainable and efficient energy use.

In work [35], the authors present two case studies using AI and ML in computational fluid dynamics (CFD) problems, specifically focusing on 2-D dam-break and 3-D fluidized bed problems. The research utilized artificial neural network (ANN) models for predicting dynamic parameters like pressure and velocity. The application of AI and ML in CFD demonstrates the potential of these technologies in complex simulation scenarios, which is directly relevant to animation, particularly in simulating fluid dynamics and other complex environmental interactions in animated scenes.

Comparative analysis of edge intelligence applications in animation

The comparative analysis of edge intelligence applications in animation focuses on how different approaches and technologies can be utilized to enhance animation design. The case studies mentioned above provide a diverse range of applications, from infrastructure monitoring to education and sustainable design. These examples demonstrate the versatility and effectiveness of edge intelligence in various aspects of animation design, highlighting its potential to transform the industry.

The authors in [36] provide a comparative analysis of various AIoT technologies, focusing on their energy efficiency. The relevance to animation lies in the need for energy-efficient edge intelligence solutions that can handle the intensive computational demands of animation design. The paper contributes to understanding how different AIoT technologies can be optimized for energy efficiency, a critical factor in animation studios where large-scale data processing is common. In [37], the authors conduct a comparative analysis of AI technologies in the FinTech sector. It's relevant to animation as it demonstrates how AI can be leveraged in various sectors, including creative industries like animation. The study's insights into AI applications in FinTech can be extrapolated to animation, particularly in how AI and edge intelligence can streamline processes and enhance creativity. Work [38] offers a comparative analysis of AI chip technologies, focusing on performance aspects. The study is pertinent to animation, where advanced chip technologies are essential for rendering and processing. The research provides valuable insights into the performance of different AI chips, which can guide the selection and implementation of hardware in animation design for optimal performance.

In work [39], the authors explore the integration of soft multimedia and edge-driven AI in landscape design, focusing on environmental analysis. Its relevance to animation lies in the application of similar technologies for creating environmentally conscious and efficient animation designs. The paper demonstrates how edge-driven AI can be used in creative processes, offering insights into sustainable and efficient design practices that can be applied in animation. A comparative analysis of edge computing technologies and devices, is provided in [40], particularly in the context of IoT and computer vision applications. It discusses the challenges and solutions in implementing edge computing in these domains. The insights from this research are valuable for animation, as it sheds light on the practical aspects of implementing edge computing in complex visual environments. The findings can be applied to optimize edge intelligence applications in animation, enhancing real-time processing and rendering capabilities. Literature [41] explores the application of distributed edge intelligence in wireless communication systems, particularly for industrial applications. It focuses on dependability assessment and spectral efficiency optimization using AI models. The study's approach to distributed edge intelligence is relevant for animation, as it provides a framework for efficient and reliable data transmission and processing. This is particularly important for collaborative and cloud-based animation projects, where seamless data exchange and processing are crucial.

Technical aspects of animation design with edge and large model

Data management and processing at the edge

In edge-assisted animation design, data management and processing are crucial for handling large volumes of animation data efficiently. The edge computing paradigm allows for the processing of data closer to the source, reducing latency and improving response times. The authors in [42] present a framework for managing and analyzing big data in smart cities, covering the entire compute continuum from edge to cloud. It focuses on edge solutions with advanced computer vision technologies for real-time data generation. The framework's approach to real-time data processing and management at the edge is applicable to animation design, where similar technologies can be used for efficient data handling and processing. In [43], the authors focus on developing an online management platform for physical education, utilizing edge computing technology to enhance the efficiency of the management system. It involves data cleaning and in-depth analysis using a modified BP neural network algorithm. The approach to data management and processing in this study can be applied to animation

design, particularly in managing large datasets and optimizing data processing workflows.

Work [44] proposes a blockchain-based data management scheme in edge computing, focusing on data trust and security. It includes a flexible and configurable blockchain architecture with features like mutual authentication protocol, smart contract, and blockchain nodes management. The scheme's emphasis on data security and trust is crucial for animation design, ensuring the integrity and protection of animation data during edge-based processing. Libiao Cui in [45] discuss the construction of a big data technology training environment for vocational education, utilizing edge computing technology for data analysis and statistics. The study's application of edge computing in data analysis and management provides insights into how similar methodologies can be adapted for managing and processing animation data efficiently. In work [46], the authors introduce a cognitive trust management model to improve security in edge computing. It focuses on maintaining the confidence of an appliance and managing the service level belief and Quality of Service (QoS). The model's approach to enhancing security and trust in edge computing is relevant for animation design, particularly in ensuring the secure and reliable processing of animation data at the edge.

Real-time rendering and interactive design

Real-time rendering and interactive design are essential components of modern animation, where edge computing can play a significant role in enhancing these aspects. The authors in [47] leverage edge computing for real-time processing of video streams in smart transportation applications. It designs a multi-thread system architecture that operates on edge devices for efficient data handling. The study's focus on realtime video analytics and efficient data processing on edge devices provides valuable insights for animation design, particularly in the context of real-time rendering and interactive elements.

Literature [48] presents a one-shot occlusion-aware real-time 3D pose estimation and inference approach, RRMP, designed for mobile edge computing devices. It focuses on real-time 3D pose estimation from RGB monocular images, crucial in VR, AR, gaming, and animation. The RRMP technique, with its real-time execution and robustness in occlusion scenarios, offers significant implications for animation design, particularly in enhancing real-time rendering and interactive design capabilities.

In [49], the authors introduce a two-stage edge scheduling framework for real-time AI applications. It creates schedules for time-critical tasks and places non real-time tasks in free slots, optimizing task execution

across edge computers. The framework's ability to handle real-time constraints is highly relevant for animation design, offering a model for efficient scheduling and execution of real-time rendering tasks in animation. An interactive system for calligraphy that reflects the writer's emotions in real-time using affective computing and visualization techniques is proposed in [50]. It uses brain wave machines to measure mental states and visualizes these emotions through animations. The system's real-time audio-visual feedback and dynamic visualization techniques provide valuable insights for animation design, especially in creating interactive and emotionally responsive animations. The authors in [51] focus on enhancing Quality of Service (QoS) in mobile edge computing through a QoS-aware Adaptive Data Dissemination Engine (QADE) paired with Dynamic Traffic Flow Control (DTFC). The study's approach to optimizing data dissemination and traffic control is crucial for animation design, particularly in managing real-time rendering and interactive design tasks efficiently.

Scalability and efficiency in large model deployment

Scalability and efficiency are key considerations in deploying large models in animation design, where edge computing can offer significant advantages. The work [52] introduces a method for railway transportation line planning and design using BIM technology, combined with IoT and edge computing for efficient data collection and analysis. The study's integration of edge computing with BIM technology for efficient data handling and visualization offers insights into scalable and efficient model deployment in animation design. Dong et al. [53] explores a novel backdoor attack on dynamic multi-exit deep neural network (DNN) models in edge computing scenarios. It demonstrates how a backdoor can be injected into a DNN model's shallow hidden layers, affecting its dynamically deployed multi-exit architectures. The research highlights the importance of security in scalable edge computing deployments, particularly relevant for large animation model deployments where data integrity and model security are paramount.

Cui et al. [54] presents HELCFL, a federated learning framework designed for high-efficiency and low-cost training in mobile-edge computing systems. It introduces a utility-driven user selection strategy and a device operating frequency determination approach to enhance performance and reduce energy costs. HELCFL's methodologies for enhancing training efficiency and reducing costs are directly applicable to the deployment of large animation models, offering a pathway to scalable and efficient model training in edge computing environments.

Limitations of large models in animation

The application of large models in animation design, despite their numerous advantages, also presents several notable shortcomings:

- (1) **Resource Intensiveness:** Large models, especially those utilizing advanced machine learning and AI algorithms, require significant computational resources. This includes high-end hardware for processing and substantial memory for data storage. This can make them less accessible for smaller studios or individual animators due to the high costs involved.
- (2) **Complexity and Skill Requirements:** The complexity of these models often demands a high level of technical expertise. Animators and designers may need to acquire additional skills in machine learning and data science to effectively use these tools, creating a steeper learning curve.
- (3) **Over-Reliance on Data:** Large models typically rely heavily on data for training and operation. In animation, this can lead to a dependency on extensive datasets, which might not always be available or may be biased, affecting the output's quality and diversity.
- (4) **Loss of Artistic Control:** With the increasing automation and AI-driven processes in animation, there's a risk of diminishing the role of human creativity and intuition. This could lead to a loss of unique artistic styles and perspectives that manually crafted animations offer.
- (5) **Ethical and Privacy Concerns:** When using AI and machine learning models that require large datasets, issues related to data privacy and ethical use of information can arise. This is particularly relevant if the data includes human subjects or proprietary content.
- (6) **Time-Consuming Training Processes:** Training large models is often a timeconsuming process, which can be a significant drawback in time-sensitive projects. This might not align well with the fast-paced nature of some animation projects.
- (7) **Generalization Issues:** There's always a risk that these models might not generalize well across different types of animation projects. A model trained on a specific style or type of animation might not perform effectively when applied to a different style, leading to limited flexibility.
- (8) **Software and Compatibility Challenges:** Integrating these large models with existing animation software and tools can be challenging. Compatibility issues may arise, requiring additional work for seamless integration.

In summary, while large models bring innovation and efficiency to animation design, they also come with challenges related to resource demands, complexity, data dependency, artistic control, ethical considerations, time for training, generalization capabilities, and software integration. These aspects must be carefully considered and managed to fully leverage the potential of large models in animation design.

Conclusion

This survey has comprehensively explored the integration of edge intelligence (EI) in animation design, particularly focusing on the challenges and opportunities associated with large model implementations. Our main work involved a detailed examination of the fundamentals of edge computing and the evolution of EI, highlighting its transformative impact on animation design. We delved into the specifics of large models in animation, discussing their evolution, current trends, and the complexities involved in their deployment. Looking forward, the survey suggests that future work should focus on enhancing the synergy between EI and animation design. This includes developing more sophisticated AI and machine learning algorithms tailored for animation, improving data management techniques at the edge, and exploring innovative approaches for real-time rendering and interactive design.

However, the utilization of large models in animation design with edge computing is still at the early stage and there are currently a number of challenges to be solved in this domain. In the upcoming study, we will further investigate how to improve the applicability or performance of large models in animation domain by introducing the domain knowledge of different animation arts since the underlying knowledge is crucial to data-driven applications in various domains [55–60]. In addition, the computational cost of large model training in animation is still large enough. Therefore, in the future work, we will further study how to optimize the animation algorithm performances with the help of edge computing technology, since edge computing has been proven an effective and efficient data loading alleviation technique [61–64]. Besides, how to develop more effective human–machine interaction ways in animation design is still another interesting topic that needs intensive study in the future work.

Acknowledgements

The work is partially supported by the Provincial quality engineering project of Anhui Provincial Colleges and Universities, Construction of the Cultivation Mode of Artistic Literacy of preschool Professionals under the environment of Master Studio System (Project number: 2022jyxm148). JZ and CH have completed the study, and also prepared its initial draft. EK has reviewed and edited the paper. MG is the research manager of this work.

Authors' contributions

JZ and CH have completed the study, and also prepared its initial draft. EK has reviewed and edited the paper. MG is the research manager of this work.

Funding

Not applicable.

Availability of data and materials

No datasets were generated or analysed during the current study.

Declarations**Ethics approval and consent to participate**

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 19 December 2023 Accepted: 23 January 2024

Published online: 21 February 2024

References

- Shi W, Cao J, Zhang Q, Li Y, Xu L (2016) Edge computing: Vision and challenges. *IEEE Internet Things J* 3(5):637–646
- Kajiya, J.T.: The rendering equation. In: *Proceedings of the 13th Annual Conference on Computer Graphics and Interactive Techniques*. 143–150 (1986)
- Zhou Z, Chen X, Li E, Zeng L, Luo K, Zhang J (2019) Edge intelligence: Paving the last mile of artificial intelligence with edge computing. *Proc IEEE* 107(8):1738–1762
- Yang X, Esquivel JA (2023) Time-aware lstm neural networks for dynamic personalized recommendation on business intelligence. *Tsinghua Sci Technol* 29(1):185–196
- Li, D., Esquivel, J.A.: Trust-aware hybrid collaborative recommendation with locality-sensitive hashing. *Tsinghua Science and Technology* (2023)
- Yang, X., Esquivel, J.A. (2023) Lstm network-based adaptation approach for dynamic integration in intelligent end-edge-cloud systems. *Tsinghua Science and Technology*
- Satyanarayanan M (2017) The emergence of edge computing. *Computer* 50(1):30–39
- Pan J, McElhannon J (2017) Future edge cloud and edge computing for internet of things applications. *IEEE Internet Things J* 5(1):439–449
- Rocha Neto A, Silva TP, Batista T, Delicato FC, Pires PF, Lopes F (2020) Leveraging edge intelligence for video analytics in smart city applications. *Information* 12(1):14
- Chen, M., Mao, S., Zhang, Y., Leung, V.C., et al. (2014) *Big Data: Related Technologies, Challenges and Future Prospects* vol. 100. Springer, ???
<https://doi.org/10.1109/MCOM.2019.1800739>
- Bellavista, P., Della Penna, R., Foschini, L., Scotece, D. (2020) Machine learning for predictive diagnostics at the edge: An iiot practical example. In: *ICC 2020–2020 IEEE International Conference on Communications (ICC)*. IEEE :1–7. <https://doi.org/10.1109/ICC40277.2020.9148684>
- Abbas N, Zhang Y, Taherkordi A, Skeie T (2017) Mobile edge computing: A survey. *IEEE Internet Things J* 5(1):450–465
- Bonomi, F., Milito, R., Zhu, J., Addepalli, S. (2012) Fog computing and its role in the internet of things. In: *Proceedings of the First Edition of the MCC Workshop on Mobile Cloud Computing* :13–16
- Hu H, Tang L (2020) Edge intelligence for real-time data analytics in an iot-based smart metering system. *IEEE Network* 34(5):68–74
- Capobianco E (2022) High-dimensional role of ai and machine learning in cancer research. *Br J Cancer* 126(4):523–532
- Khuat, T.T., Bassett, R., Otte, E., Grevis-James, A., Gabrys, B. (2023) Applications of machine learning in biopharmaceutical process development and manufacturing: Current trends, challenges, and opportunities. *arXiv preprint arXiv:2310.09991*
- Ding L, Wei G, Zhang K (2022) Animation design of multisensor data fusion based on optimized AVOD algorithm. *J Sens* 2022:11. Article ID: 9683939
- Rathore MM, Shah SA, Shukla D, Bentafat E, Bakiras S (2021) The role of ai, machine learning, and big data in digital twinning: A systematic literature review, challenges, and opportunities. *IEEE Access* 9:32030–32052
- Wang H, Qu Z, Zhou Q, Zhang H, Luo B, Xu W, Guo S, Li R (2021) A comprehensive survey on training acceleration for large machine learning models in iot. *IEEE Internet Things J* 9(2):939–963
- Soelistono, S., et al. (2023). Educational technology innovation: Ai-integrated learning system design in ails-based education. *Influence Int J Sci Rev* 5(2):470–480
- Zhou Y, Zhou Y, Liu W, Huang L (2020) Design and realisation of virtual experiment teaching system for transplanting machine. *Int J Continuing Eng Educ Life Long Learn* 30(1):15–26
- Shrestha H, Puviyarai T, Sodanapalli S, Dhasarathan C (2021) Evolution of fog computing applications, opportunities, and challenges: A systematic review. *Int J Fog Comput (IJFC)* 4(1):1–17
- Zhang R (2023) Using artificial intelligence assistant technology to develop animation games on iot. *Comput Sci Inf Syst* 00:21–21
- Yang, Y., Dai, J., Liu, S. (2023) Research on real-time interaction and control access technology of communication information of power iot gateway based on edge intelligence technology. In: *2023 Asia-Europe Conference on Electronics, Data Processing and Informatics (ACEDPI)*. 519–524. IEEE
- Ye, C. (2022) Real-time image edge detection system design and algorithms for artificial intelligence fpgas. In: *2022 International Conference on Artificial Intelligence of Things and Crowdsensing (AloTCs)*, pp. 476–481 (2022). IEEE
- Chen M-Y, Wu H-T (2021) Real-time intelligent image processing for the internet of things. *J Real-Time Image Proc* 18:997–998
- Zaidi SAR, Hayajneh AM, Hafeez M, Ahmed Q (2022) Unlocking edge intelligence through tiny machine learning (tinyml). *IEEE Access* 10:100867–100877
- Gross WJ, Meyer BH, Ardakani A (2020) Hardware-aware design for edge intelligence. *IEEE Open J Circuits Syst* 2:113–127
- Jiang K, Sun C, Zhou H, Li X, Dong M, Leung VC (2021) Intelligenceem-powered mobile edge computing: Framework, issues, implementation, and outlook. *IEEE Network* 35(5):74–82
- Lim, W.Y.B., Xiong, Z., Niyato, D., Cao, X., Miao, C., Sun, S., Yang, Q. (2022) Realizing the metaverse with edge intelligence: A match made in heaven. *IEEE Wireless Communications*
- Tilon S, Nex F, Vosselman G, Llave I, Kerle N (2022) Towards improved unmanned aerial vehicle edge intelligence: A road infrastructure monitoring case study. *Remote Sensing* 14(16):4008
- Tang T, Li P, Tang Q (2022) New strategies and practices of design education under the background of artificial intelligence technology: online animation design studio. *Front Psychol* 13:767295
- Bochare R, Bagora P (2022) Comparative analysis of green building rating systems for residential house: A case study. *ECS Trans* 107(1):7091
- Rahmadyani H, Fahri M (2022) A comparative analysis of building energy performance assessment on campus buildings (case study: Universitas Bangka Belitung). *The 4th International Conference on Green Energy and Environment*. <https://doi.org/10.1088/1755-1315/1108/1/012053>
- Ansari A, Boosari S, Mohaghegh S (2020) Successful implementation of artificial intelligence and machine learning in multiphase flow smart proxy modeling: two case studies of gas-liquid and gas-solid cfd models. *J Pet Environ Biotechnol* 101(1):1–8
- Jevremovic, A., Kostic, Z., Perakovic, D. (2023) Energy-efficient edge intelligence: A comparative analysis of aiot technologies. *Mobile Networks and Applications*, 1–9
- Singh, A.K., Sharma, P.M., Bhatt, M., Choudhary, A., Sharma, S., Sadhukhan, S. (2022) Comparative analysis on artificial intelligence technologies and its application in fintech. In: *2022 International Conference on Augmented Intelligence and Sustainable Systems (ICAIS)* :570–574 . IEEE
- Gao, R., Song, M. (2021) Performance comparative analysis of artificial intelligence chip technology. In: *2021 2nd International Conference on Computer Engineering and Intelligent Control (ICCEIC)*:149–153 . IEEE
- Ma B, Dong Y, Liu H, Cao Z (2022) Soft multimedia assisted new energy productive landscape design based on environmental analysis and edge-driven artificial intelligence. *Soft Comput* 26(23):12957–12967

40. Rohith, M., Sunil, A., et al. (2021) Comparative analysis of edge computing and edge devices: key technology in iot and computer vision applications. In: 2021 International Conference on Recent Trends on Electronics, Information, Communication & Technology (RTEICT). :722–727. IEEE
41. Danfeng S (2022) Distributed edge intelligence enabled wireless communication systems serving industrial applications. VDI Verlag Düsseldorf 1278. <https://doi.org/10.51202/9783186278081>
42. Cavicchioli R, Martoglia R, Verucchi M et al (2022) A novel real-time edge-cloud big data management and analytics framework for smart cities. *J Univ Comput Sci* 28(1):3–26
43. Sun W, Gao Y (2021) The design of university physical education management framework based on edge computing and data analysis. *Wirel Commun Mob Comput* 2021:1–8
44. Zhaofeng, M., Xiaochang, W., Jain, D.K., Khan, H., Hongmin, G., Zhen, W. (2019) A blockchain-based trusted data management scheme in edge computing. *IEEE Transact Industr Inform* 16(3):2013–2021
45. Cui L (2022) Construction of big data technology training environment for vocational education based on edge computing technology. *Wirel Commun Mob Comput* 2022:1–9
46. Ganesh, D., Suresh, K., Kumar, M.S., Balaji, K., Burada, S. (2022) Improving security in edge computing by using cognitive trust management model. In: 2022 International Conference on Edge Computing and Applications (ICECAA):524–531 IEEE
47. Ke R, Zhuang Y, Pu Z, Wang Y (2020) A smart, efficient, and reliable parking surveillance system with edge artificial intelligence on iot devices. *IEEE Trans Intell Transp Syst* 22(8):4962–4974
48. Hossain, M.I., Akhter, S., Hossain, M.D., Hong, C.S., Huh, E.-N. (2023) Multi-person 3d pose estimation in mobile edge computing devices for real-time applications. In: 2023 International Conference on Information Networking (ICOIN):673–677. IEEE
49. Fadahunsi, O., Ma, Y., Maheswaran, M. (2021) Edge scheduling framework for real-time and non real-time tasks. In: Proceedings of the 36th Annual ACM Symposium on Applied Computing:719–728
50. Wang C-M, Chen Y-C (2020) Design of an interactive mind calligraphy system by affective computing and visualization techniques for real-time reflections of the writer's emotions. *Sensors* 20(20):5741
51. Kaur G, Singh B, Batth RS (2023) Design of an efficient QoS aware adaptive data dissemination engine with DTFC for mobile edge computing deployments. *Int J Comput Netw Appl* 10(5):728–744
52. Wu, S., Zhang, X., et al. (2022) Visualization of railway transportation engineering management using bim technology under the application of internet of things edge computing. *Wireless Communications and Mobile Computing* 2022
53. Dong L, Qiu J, Fu Z, Chen L, Cui X, Shen Z (2023) Stealthy dynamic backdoor attack against neural networks for image classification. *Appl Soft Comput* 149:110993
54. Cui, Y., Cao, K., Zhou, J., Wei, T. (2022) Helcfl: High-efficiency and low-cost federated learning in heterogeneous mobile-edge computing. In: 2022 Design, Automation & Test in Europe Conference & Exhibition (DATE):1227–1232. IEEE
55. Liu Y, Wu H, Rezaee K, Khosravi MR, Khalaf Ol, Khan AA, Ramesh D, Qi L (2022) Interaction-enhanced and time-aware graph convolutional network for successive point-of-interest recommendation in traveling enterprises. *IEEE Trans Industr Inf* 19(1):635–643
56. Qi L, Liu Y, Zhang Y, Xu X, Bilal M, Song H (2022) Privacy-aware point-of-interest category recommendation in internet of things. *IEEE Int Things J* 9(21):21398–21408
57. Wang F, Zhu H, Srivastava G, Li S, Khosravi MR, Qi L (2021) Robust collaborative filtering recommendation with user-item-trust records. *IEEE Transact Comput Soc Syst* 9(4):986–996
58. Kong, L., Li, G., Rafique, W., Shen, S., He, Q., Khosravi, M.R., Wang, R., Qi, L. (2022) Time-aware missing healthcare data prediction based on arima model. *IEEE/ACM Transactions on Computational Biology and Bioinformatics*
59. Wang, F., Wang, L., Li, G., Wang, Y., Lv, C., Qi, L. (2021) Edge-cloud-enabled matrix factorization for diversified apis recommendation in mashup creation. *World Wide Web*: 1–21
60. Qi, L., Lin, W., Zhang, X., Dou, W., Xu, X., Chen, J. (2022) A correlation graph based approach for personalized and compatible web apis recommendation in mobile app development. *IEEE Transactions on Knowledge and Data Engineering*
61. Kong, L., Wang, L., Gong, W., Yan, C., Duan, Y., Qi, L. (2021) Lsh-aware multitype health data prediction with privacy preservation in edge environment. *World Wide Web* :1–16
62. Yang, Y., Yang, X., Heidari, M., Khan, M.A., Srivastava, G., Khosravi, M., Qi, L. (2022) Astream: Data-stream-driven scalable anomaly detection with accuracy guarantee in iiot environment. *IEEE Transactions on Network Science and Engineering*
63. Wang F, Li G, Wang Y, Rafique W, Khosravi MR, Liu G, Liu Y, Qi L (2023) Privacy-aware traffic flow prediction based on multi-party sensor data with zero trust in smart city. *ACM Trans Internet Technol* 23(3):1–19
64. Qi L, Xu X, Wu X, Ni Q, Yuan Y, Zhang X (2023) Digital twin enabled 6g mobile network video streaming using mobile crowdsourcing. *IEEE J Sel Areas Commun* 41(10):3161–3174

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.