



AI Empowering Museums: Current Applications, Challenges, and Future Trends

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Abstract. This paper explores the current applications of artificial intelligence (AI) technology in the global museum sector, the challenges faced, and future development trends. Through analysis of intelligent guidance, cultural heritage protection, virtual exhibitions, and other aspects, combined with practical case studies, it demonstrates how AI technology enhances museum operational efficiency, enriches visitor experiences, and promotes cultural dissemination and innovation. The paper also discusses bottlenecks encountered in technology application, personnel transformation needs, and ethical and legal issues, proposing corresponding strategies and recommendations to provide references for the digital transformation and sustainable development of museums.

Keywords: Artificial Intelligence; Museums; Cultural Heritage Protection; Intelligent Guidance; Virtual Exhibitions; Technology Integration

1 Introduction

1.1 Research Background and Significance

In the digital age, the rapid development of AI technology is profoundly transforming various industries. Museums, as repositories of human civilization and important carriers of cultural heritage, are also deeply influenced by AI technology. On one hand, traditional museums face challenges such as the difficulty of managing collections and the diversification of visitor demands. On the other hand, AI technology offers opportunities for museums to innovate service models, improve operational efficiency, and enhance cultural dissemination. Therefore, studying the current applications and trends of AI technology in museums is of great significance for promoting the modernization of museums, meeting visitor cultural needs, and promoting the upgrading of the cultural industry.

1.2 Domestic and International Research Status

Research on the integration of AI technology and museums started earlier abroad, covering multiple fields such as cultural heritage protection, digital display, and visitor experience, with certain achievements, such as using computer vision technology to

assess the degree of cultural relic damage and constructing immersive visiting experiences through virtual reality technology[1]. Although domestic research started slightly later, it has gradually deepened in theoretical exploration and application practice. Scholars focus on the specific applications of AI technology in collection management, exhibition display, and educational promotion, and actively develop cultural and creative products to expand the channels of cultural dissemination. However, there are still problems in current domestic and international research, such as insufficient depth and breadth of technology application, lack of in-depth interdisciplinary research, and weak attention to social impact and ethical issues. It is necessary to further strengthen technology research and development, promote interdisciplinary communication and cooperation, and deeply explore related social and ethical issues.

2 Current Applications of AI Technology in Museums

2.1 Intelligent Guidance and Interpretation Services

2.1.1 Case Analysis of Intelligent Guidance Systems.

The British Museum has introduced an AI-powered intelligent guidance system that leverages Bluetooth beacons, Wi-Fi positioning, and indoor mapping technology to accurately locate visitors within the museum. This allows visitors to always know their current location and the surrounding facilities, avoiding getting lost. The system analyzes personal interest preferences, visit time constraints, and previously viewed exhibits filled out by visitors, using AI algorithms to tailor personalized visit routes. For example, visitors interested in ancient Egyptian artifacts will be prioritized to recommend relevant key artifacts and plan reasonable routes to ensure efficient visits within limited time. In addition, the system provides detailed and vivid audio interpretations for each exhibit, covering basic information about the exhibits, historical and cultural background, artistic value, and historical stories, and supports multiple languages to meet the needs of visitors from different countries and regions, enabling visitors to gain a deep understanding of the connotations of the exhibits and improve visit satisfaction[2].

2.1.2 Application Examples of AI Digital Human Interpretation.

The application of AI digital humans by Shiyu Technology at the Du Fu Thatched Cottage Museum in Chengdu demonstrates its unique charm. The digital human's image highly restores the image of Du Fu. Through advanced computer graphics technology and historical research, it presents the classic image of Du Fu in ancient costume and holding a book, with delicate facial expressions and natural movements, enhancing cultural immersion. It has a strong natural language processing capability and can accurately understand and answer visitors' questions about Du Fu's poetry creation, life experiences, and the historical and cultural background of the Du Fu Thatched Cottage, and can also expand related knowledge to guide visitors to think deeply. At the same time, the AI digital human can customize personalized tour routes and interpretation content based on visitors' interests, visit time, and other factors, and adjust the

interpretation rhythm and content in real-time according to feedback to provide considerate services, enriching the museum's tour formats and improving the quality and efficiency of interpretation services.

2.2 Cultural Heritage Protection and Restoration

2.2.1 The Role of AI Technology in Cultural Heritage Protection.

The Palace Museum uses AI technology to build a comprehensive, real-time environmental monitoring system. Through a large number of sensors, it collects real-time data on environmental parameters such as temperature, humidity, lighting, and air quality. AI algorithms analyze the data and issue timely warnings to remind staff to take measures, effectively preventing environmental factors from causing damage to cultural relics. At the same time, AI technology analyzes information on the material, craftsmanship, storage environment, and historical disease data of cultural relics to establish a disease prediction model. It can predict the types and development trends of potential diseases in cultural relics in advance. For example, by analyzing factors such as the aging degree and acidity of paper cultural relics, it predicts potential diseases such as brittleness and mold, and provides preventive suggestions to help cultural heritage protection personnel formulate protection plans in advance and reduce the risk of cultural relic damage.

2.2.2 AI-assisted Technology in Cultural Relic Restoration.

In the restoration of the murals at the Mogao Caves in Dunhuang, AI technology plays an important auxiliary role. Through high-resolution image acquisition equipment, comprehensive and detailed image acquisition of the murals is carried out. AI image recognition and analysis algorithms are used to deeply analyze the color, texture, pattern, and other information of the murals, identify the location, shape, and scope of the damaged parts, and compare them with the well-preserved parts to infer the original appearance of the damaged parts, providing reference solutions for restorers. At the same time, the AI system can provide restorers with multiple restoration solutions based on the damage condition of the cultural relics, material characteristics, historical background, and other multi-faceted information, combined with a large number of restoration cases and expert experience. It also assesses and predicts the feasibility, restoration effect, and potential risks of each solution to assist restorers in decision-making and improve the quality and effect of restoration.

2.3 Virtual Exhibitions and Immersive Experiences

2.3.1 Construction and Application of Virtual Exhibition Platforms.

The Louvre in France has used advanced technologies such as AI and VR to create online exhibitions, breaking through the time and space limitations of traditional exhibitions and expanding the audience. AI algorithms analyze cultural relic data to provide personalized recommendations of exhibits and exhibition information based on visitor interests and browsing history. They also intelligently classify and label exhibits for

easy searching and understanding by visitors. VR technology creates an immersive experience for visitors, allowing them to fully appreciate cultural relics in a 360-degree view, feel the charm of cultural relics, and restore real exhibition scenes to enhance the atmosphere of the visit.

2.3.2 Integration of AI Technology in Immersive Exhibition Experiences.

The "Light of Ancient Shu" exhibition at the Shanghai Museum integrates AI with AR and holographic projection technology to create an immersive experience. Visitors can download AR applications on their mobile phones or tablets, scan cultural relics or exhibition boards, and display three-dimensional models of cultural relics on the screen. They can observe details from different angles and learn relevant information. AI technology makes AR applications smarter in recognizing cultural relics and visitor operations, providing accurate interactive content. Holographic projection technology, in combination with AI technology, creates realistic historical scenes. For example, the ancient Shu sacrificial scene uses AI technology to analyze historical data and provide precise scene design and character movement simulation for holographic projection, allowing visitors to feel as if they have traveled through time and enhancing their sense of participation and immersion.

3 Opportunities and Challenges of AI Technology in Museums

3.1 Opportunities

3.1.1 Enhancing Visitor Experience.

AI technology enables museums to provide personalized tours by deeply analyzing visitor data to build interest profiles and customize tour routes and interpretation content, meeting individual needs and improving visit efficiency. The integration of AI with AR, VR, and other technologies creates immersive interactive environments. For example, visitors can scan exhibits to obtain rich information and participate in ancient scene simulation activities, enhancing the fun and participation of visits. In addition, intelligent voice guidance and AI digital human interpretation provide detailed introductions and knowledge explanations of exhibits in a lively language. They can also adjust content in real-time based on visitor questions and feedback, deepening visitors' understanding and memory of knowledge[3].

3.1.2 Assisting Cultural Heritage Research and Protection.

AI technology can quickly process large amounts of cultural heritage data, automatically recognize and classify cultural relic images, texts, audio, and other materials, extract key information, and establish cultural relic knowledge graphs. This helps researchers understand the relationships between cultural relics, such as their age, cultural heritage, and craftsmanship similarities, providing new perspectives and methods for research. In the formulation of cultural relic restoration plans, AI provides restorers

with multiple restoration solutions through digital analysis of cultural relic damage, combined with historical data and restoration experience. It also predicts the restoration effect of each solution to assist restorers in decision-making. In addition, AI's real-time monitoring and data analysis of cultural relic storage environments predict potential risks and provide data support and scientific basis for cultural heritage protection workers to formulate protection measures in advance.

3.1.3 Promoting Museum Innovation and Development.

The integration of AI technology with multimedia, virtual reality, augmented reality, and other technologies brings new exhibition forms to museums. For example, immersive exhibitions allow visitors to feel the historical and cultural atmosphere as if they were there, and interactive exhibitions stimulate visitor enthusiasm through interactive devices and games. In terms of operational models, AI achieves intelligent collection management through real-time monitoring and intelligent scheduling of collections, improving management efficiency[4]. It also reduces labor costs and improves operational efficiency through automated ticket management and people flow monitoring functions. In terms of cultural dissemination methods, AI expands the channels and scope of museum dissemination. Through online platforms and social media, cultural relic resources and exhibition content are digitally presented to global audiences. It can also carry out personalized cultural dissemination according to visitor needs, improving the targeting and effectiveness of dissemination.

3.2 Challenges

3.2.1 Technical Bottlenecks.

There are issues with the accuracy of image recognition in AI technology applications in museums. For cultural relics that are ancient, severely damaged, or have unclear features, misjudgments may occur. For example, it is difficult to accurately identify the original style and author information of ancient calligraphy and painting works that have been repaired multiple times[5]. The experience of virtual exhibitions is affected by network speed and device performance. Unstable networks or low device configurations can cause visitors to experience lag and slow loading during viewing. Moreover, the interaction and realism of virtual exhibitions need to be improved at present. In addition, the security of artificial intelligence systems cannot be ignored. Once the large amount of precious cultural relic information and visitor data stored in museums are leaked or attacked by hackers, serious consequences will follow. It is necessary to strengthen security protection.

3.2.2 Personnel Transformation and Knowledge Update.

The application of AI technology poses new requirements for the capabilities and qualities of museum staff. Staff members need to possess professional knowledge in cultural heritage protection, exhibition planning, interpretation, and other fields, as well as AI technology and data analysis skills. However, many staff members currently lack relevant training and knowledge, which affects the effectiveness of technology

application. Museums need to strengthen staff training to help them improve AI technology and data analysis skills. At the same time, they should reasonably arrange positions to avoid redundancy or loss of personnel and actively introduce talents with relevant professional backgrounds to strengthen the technical team.

3.2.3 Ethical and Legal Issues.

The application of AI technology raises ethical and legal issues such as data privacy protection, AI creation copyright ownership, and algorithm bias. Museums must ensure data security and privacy when collecting and using visitor data and cultural relic information. They should establish strict management systems and comply with relevant laws and regulations. The copyright ownership of AI-created works is not clearly defined by law, involving the interests of multiple parties, and requires further research and legislation. Algorithm bias is also a problem that cannot be ignored. It is necessary to ensure the diversity and representativeness of training data, strictly assess and verify algorithms, and strengthen research on transparency and interpretability to avoid negative impacts on cultural relic evaluation and visitor services.

4 Future Trends of AI Technology in Museums

4.1 Technology Integration and Innovation

4.1.1 Deep Integration of AI with IoT and Big Data.

In the intelligent management of museums, the integration of AI with IoT and big data allows for real-time monitoring of exhibition hall environmental indicators through sensor networks. Big data technology manages and stores data, while AI analyzes and mines it to make intelligent decisions and management. For example, predicting equipment failures and optimizing the layout of exhibits. In precision marketing, IoT collects visitor behavior data, big data analysis builds user portraits, and AI technology realizes personalized marketing promotion[6]. In personalized services, IoT and big data technologies are used to understand visitor needs and states in real-time, and AI provides personalized services to improve visitor satisfaction and loyalty.

4.1.2 Expansion of Emerging Technology Applications in Museums.

Blockchain technology has great potential in cultural relic tracing. By storing cultural relic information on the chain, an unchangeable cultural relic identity information and historical record are formed, ensuring the legality and authenticity of the cultural relic source. Quantum computing technology has important application prospects in data security and exhibition innovation. Its powerful computing power and encryption characteristics provide high-level protection for museum data security and can be used for exhibition innovation to bring new experiences to visitors.

4.2 Upgrading of Personalized and Customized Services

4.2.1 Creating Personalized Visit Experiences with AI.

Using AI technology, museums can provide customized tours, recommendations, and interactive experiences based on visitor interests, behaviors, and preferences. In customized tours, AI analyzes visitor data to build interest portraits and customizes tour routes and interpretation content, dynamically adjusting according to real-time needs and feedback. In recommendation services, AI analyzes visitor interest portraits and historical visit data to recommend exhibitions, activities, and cultural and creative products that match their interests. AI also brings changes to the interactive experiences of museums. By integrating with AR, VR, holographic projection, and other technologies, it creates rich and immersive interactive experiences.

4.2.2 Service Innovation to Meet the Needs of Different Visitor Groups.

Targeting special groups such as children, the elderly, and people with disabilities, museums use AI technology to provide differentiated services. For children, interactive games, animated displays, voice stories, and other forms of exhibitions and educational activities are developed to stimulate learning interest. For the elderly, considerate services such as reasonable tour route planning, large font display, and high-volume playback functions are provided, and health monitoring devices are developed. For visually impaired people, voice guidance and Braille displays are provided, and for hearing-impaired people, subtitle generation and sign language translation services are provided to meet the needs of different groups and reflect humanitarian care.

4.3 Strengthening of International Cooperation and Cultural Exchange

4.3.1 AI-assisted International Museum Cooperation Projects.

AI technology plays an important role in transnational cultural relic research. By digitizing and analyzing the cultural relics in both museums, it helps researchers discover the similarities and differences between cultural relics and gain a deeper understanding of the inheritance of craftsmanship and cultural exchange. In the planning of joint exhibitions, AI technology integrates and analyzes the cultural relic resources of both museums. It provides scientific suggestions based on the historical background, artistic value, and cultural connotation of cultural relics, optimizes the selection and display design of exhibits, and enhances the fun and interactivity of exhibitions.

4.3.2 Promoting the Display and Dissemination of Global Cultural Diversity.

AI technology displays global cultural heritage through digital means. Museums convert cultural relics and cultural sites into digital models for display, broadening the cultural horizons of visitors. At the same time, AI technology uses personalized recommendations and social media dissemination to let more people understand the diversity of global cultures. It can also be used for the creative dissemination of cultural heritage to attract more attention.

5 In-depth Case Analysis

5.1 Analysis of Typical Foreign Museum AI Applications

5.1.1 AI Practices at the Metropolitan Museum of Art, USA.

The Metropolitan Museum of Art in the United States has used AI technology to conduct in-depth research and interpretation of artworks. Through the collection of digital images of artworks and analysis by deep learning algorithms, it identifies the style, school, author, and other information of artworks, infers the creation date and background, and discovers hidden information. In exhibition planning, big data analysis technology is used to collect and analyze visitor data, predict visitor attention, and optimize exhibition layout and display. In visitor interaction, a smart tour application is launched, providing real-time voice guidance and question-and-answer services, and using AR technology to create immersive interactive experiences.

5.1.2 AI Application Achievements at the Natural History Museum, UK.

The Natural History Museum in the UK has used AI image recognition and IoT technology to achieve intelligent management of specimens in specimen management, quickly and accurately identifying specimen information and real-time monitoring of storage environments. In science popularization education, interactive science popularization education projects are developed, using VR, AR technology combined with AI voice interpretation and interactive games to create immersive science popularization experiences. In scientific research cooperation, AI technology is used to jointly conduct natural science research with global research institutions and universities, analyze and process biological specimen data, monitor changes in biodiversity, and reconstruct the morphology and evolutionary process of ancient biological fossils.

5.2 Analysis of Typical Domestic Museum AI Applications

5.2.1 AI Innovation Applications at the Palace Museum.

The Palace Museum has used AI technology to establish a digital archive of cultural relics in cultural heritage protection, real-time monitoring and assessment of the preservation status of cultural relics, and simulation to assist cultural relic restoration decision-making. In the development of cultural and creative products, AI technology is used to explore the cultural connotations of cultural relics, and creative and characteristic cultural and creative products are developed. The elements of cultural relics are combined with modern technology to develop intelligent cultural and creative products. In digital display, AI is integrated with VR and AR technology to create immersive digital exhibitions, achieving dynamic display and interactive experiences of cultural relics.

5.2.2 AI Exploration Practices at the Shaanxi History Museum.

The Shaanxi History Museum has introduced an AI smart tour system in smart tour guidance, providing personalized and convenient tour services. It recommends

personalized tour routes and key exhibits based on visitor interests and visit history. In exhibition innovation, AI technology is integrated with multimedia, virtual reality, and other technologies to create innovative and interactive exhibitions, achieving interaction between cultural relics and visitors. In cultural dissemination, cultural relic resources and exhibition content are digitally presented through online platforms and social media. Online exhibitions and virtual tour functions are developed, and AI algorithms are used to accurately recommend cultural content to expand the influence of museums.

6 Development Strategies and Suggestions

6.1 Museum Self-development Strategies

6.1.1 Strengthening Technology Investment and Talent Cultivation.

Museums should increase investment in AI technology, purchase advanced equipment, participate in scientific research projects, and promote technological innovation and development. At the same time, cultivate compound talents who understand both cultural relics and technology, strengthen internal staff training, introduce professional talents with AI technology background, and establish talent cultivation cooperation mechanisms with universities.

6.1.2 Improving the Management and Evaluation System of AI Applications.

A complete management process for AI applications should be established. Before implementation, demand analysis and feasibility studies should be carried out, project implementation plans should be formulated, and during the implementation process, supervision and management should be strengthened. Attention should also be paid to daily maintenance and updates. A scientific and reasonable evaluation index system for AI applications should be established to regularly evaluate and analyze, identify problems and improve, ensure the effective application of technology, and achieve sustainable development.

6.2 Government and Industry Support Measures

6.2.1 Policy Support and Financial Assistance.

The government should introduce policies and provide financial support, set up special funds to encourage museums to carry out AI technology application projects, provide tax preferential policies to reduce museum operating costs, and guide social capital to participate in the AI construction of museums, promoting the deep integration of technology and culture.

6.2.2 Developing Industry Standards and Norms.

Industry standards and norms for the application of AI technology in museums should be developed. Clear requirements for data collection, storage, use, and sharing

should be established to ensure data security. Service quality standards should be developed to ensure that visitors receive high-quality service experiences.

6.3 Building a Collaborative Innovation Mechanism of Industry, Academia, and Research

6.3.1 Strengthening Cooperation with Research Institutions and Universities.

Museums should establish close cooperation with research institutions and universities to jointly carry out technological research and application research, play to the strengths of all parties, achieve complementary resource sharing, and jointly carry out research projects and technological development in cultural heritage protection, exhibition display, and other aspects.

6.3.2 Promoting Collaborative Innovation of Industry, Academia, Research, and Application.

A collaborative innovation platform of industry, academia, research, and application should be established to integrate various resources and carry out activities such as project research and development, talent training, and technical exchanges, promoting the application and industrial development of technology. Various parties should be organized to undertake projects, carry out joint talent training projects, and hold academic seminars and other activities to promote exchanges and cooperation as well as the promotion of technology.

7 Conclusion

This paper comprehensively and in-depth explores the current applications of AI technology in the global museum field, the opportunities and challenges faced, and future trends. Through multi-dimensional analysis and case studies, it demonstrates the transformative impact of AI technology on museums in areas such as intelligent guidance, cultural heritage protection, and virtual exhibitions. It also analyzes the challenges of technical bottlenecks, personnel transformation, and ethical and legal issues, and proposes strategies and suggestions for the digital transformation of museums.

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