

Research and Application of Digital Protection and Virtual-Real Integration Display Technology for Cliff Inscriptions in Western Liaoning Enabled by AI

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Abstract

As the core physical remains of the integration of national culture and Buddhist art in the Liao and Jin Dynasties, the cliff stone carvings in western Liaoning are very representative historical and cultural treasures in Liaoning Province, carrying the unique historical value of the integration of northern nomadic culture and central plains farming culture. For a long time, the open-air preservation environment in the field has caused the stone carvings to continue to suffer from multiple damages such as physical weathering, rainwater erosion, biological attachment and man-made destruction, and the damage of cultural relics is becoming more and more serious. The traditional protection and communication mode of manual recording, entity reinforcement and static display has many shortcomings, such as low collection accuracy, lagging monitoring, single communication form and inefficient transformation of cultural tourism, which cannot take into account the dual development needs of long-term retention of cultural relics and cultural activation and communication. With the rapid iteration of artificial intelligence, three-dimensional reconstruction and VR/AR virtual-real fusion technology, it provides a new technical path for the digital protection and innovative dissemination of field stone cultural relics. This paper takes the two core cliff stone carving groups in western Liaoning as the research carrier, integrates multiple technologies such as UAV tilt photography, 3D laser scanning, deep learning image recognition, lightweight virtual and real interactive development, and constructs a whole process digital technology system covering high-precision digital archiving, intelligent monitoring of stone carving diseases, virtual repair of incomplete texture, and immersive virtual and real display. By building a dedicated stone carving digital resource database, the VR immersive display system of the venue and the mobile AR navigation applet are developed to effectively solve the industry pain points such as the difficulty of field stone carving data collection, low disease identification efficiency, single display experience, and insufficient cultural and tourism empowerment. The practical results show that AI digital technology can accurately retain the micron-level texture and shape details of stone carvings, and realize the dynamic quantitative monitoring of cultural relics diseases. The virtual and real fusion display mode can break the limitation of time and space, and significantly improve the awareness of mass culture and the conversion rate of cultural and tourism resources.

Keywords

Artificial intelligence, cliff inscriptions, digitization, integration of virtual and real, Cultural Revitalization.

1. Analysis of the Preservation Status and Digitalization Needs of Cliff Inscriptions in Western Liaoning

1.1. Overview and Current State of Damage of Cliff Inscriptions in Western Liaoning

The western Liaoning is the core circle of Liao and Jin cultural integration. The special historical location has created unique cliff stone carving cultural relics. The cliff stone carvings in western Liaoning are mainly concentrated in the two major areas of Haitang Mountain in Fuxin and Tiecha Mountain in Benxi. The creation of statues spans the three historical periods of Liao, Jin and Qing Dynasties. There are more than 300 complete and incomplete statues, covering multiple types such as Buddha statues, Bodhisattvas, protection statues, and text inscriptions. Its carving knife method is rough and vigorous, and its shape has both the heroic characteristics of the northern nomadic people and the elegant charm of the Central Plains Buddhist art. It truly records the historical context of the integration of frontier ethnic groups in western Liaoning, the spread of Buddhist culture and the development of ancient stone carving technology. It is an irreplaceable material for studying the history and culture of Northeast Liaoning and Jin Dynasties, and has been listed as a key cultural relics protection unit in Liaoning Province.

Due to the long-term exposure of stone carvings to the wild natural environment, combined with the complex regional climate and the interference of human activities, the cultural relics are facing the risk of continuous and irreversible damage. The main types of diseases can be divided into four categories. First, physical weathering diseases, the continental monsoon climate characteristics in western Liaoning are significant. The temperature difference between winter and summer can reach more than 60 °C, and the temperature difference between day and night is very large. The long-term thermal expansion and cold contraction lead to the cracking of the surface stone of the stone carving, flake spalling, a large number of small statues with blurred facial contours and incomplete limbs, and the overall integrity has been seriously damaged. Second, water erosion and freeze-thaw diseases. In summer, concentrated rainfall carries mountain sediment to scour the surface of stone carvings. After rainwater seeps into the stone crevices, the low temperature in winter freezes and expands, and the high temperature in summer melts and repeatedly acts, resulting in a large area of stone inscriptions. Diffusely blurred, a large number of precious written historical materials cannot be identified. Third, biological erosion diseases, cliff wet environment breeding a large number of mosses, lichens and other microorganisms, at the same time, the mountain shrubs, weeds roots deep into the stone, continue to destroy the stability of stone structure, accelerate the process of stone weathering damage. Fourth, man-made damage diseases, early years of disorderly cultural relics rubbing behavior, tourists close touch climbing, random painting and other uncivilized behavior, causing permanent damage to the stone carvings, some statue details completely lost.

The traditional cultural relic protection model primarily involves manual on-site cleaning, local reinforcement, and paper-based recording. This approach only achieves phased and reactive protection and cannot fundamentally preserve the original appearance of stone carvings. Additionally, methods such as manual drawing, ordinary photography, and rubbing recording have extremely low accuracy, making it difficult to capture the subtle textures and structural features of stone carvings. Furthermore, paper archives and rubbing materials are prone to moisture, damage, and loss, making it impossible to achieve permanent preservation and dynamic tracing of cultural relic data. This approach is difficult to adapt to the development needs of modern long-term cultural relic protection.

1.2. Core Requirements for Digital Preservation and Integrated Virtual and Real Display

1.2.1. Long-term Preventive Conservation Needs for Cultural Relics

The destruction process of cliff stone carvings in western Liaoning continues to intensify. It is urgent to rely on high-precision digital technology to complete the all-round collection of the original data of cultural relics, build permanently retained digital archives, realize the sustainable preservation of cultural relics ontology data, and avoid the risk of complete loss of cultural relics caused by natural damage. At the same time, the traditional manual inspection has low efficiency and strong subjectivity, and cannot quantify the degree of damage and track the trend of damage. The introduction of artificial intelligence image recognition technology can realize the automation, precision and normalization monitoring of stone carving diseases, dynamically record the core data such as disease location, type and damaged area, and form an annual damage comparison report, which can provide accurate and quantitative data support for the preventive protection, restoration plan formulation and maintenance effect evaluation of cultural relics, and promote the transformation of stone carving protection from passive repair to active prevention.

1.2.2. Cultural Dissemination and Public Science Popularization Needs

Currently, the dissemination of stone carving culture in western Liaoning primarily relies on static displays in offline exhibition halls, utilizing traditional forms such as display boards, paper photographs, and brief introductions to cultural relics. These displays are monotonous and lack interactivity. Visitors are unable to intuitively perceive the original cliff environment where the stone carvings are located, the spatial layout of the statues, and the details of the carving techniques. This makes it difficult for them to deeply understand the historical connotations of ethnic integration and the spread of Buddhist culture during the Liao and Jin dynasties, greatly reducing the effectiveness of cultural popularization. At the same time, traditional display modes are highly constrained by time and space, making it impossible to achieve regular online dissemination and limiting the scope of cultural radiation. There is an urgent need to break through the barriers of time and space through virtual and real fusion technologies such as VR panoramic replication and AR dynamic restoration, to restore the original appearance of stone carvings in an immersive and interactive display format. This can be complemented by intelligent voice commentary and cultural popularization animations, lowering the threshold for public cultural understanding and enhancing public awareness and dissemination of western Liaoning's stone carving culture.

1.2.3. Demand for Upgrading and Development of Regional Cultural Tourism Industry

Liaoxi cliff carvings have high-quality cultural and tourism resource endowments, but the current resource conversion rate is less than 30 % of similar cultural heritage in China. The core shortcomings are single experience form, insufficient interaction, weak secondary consumption and limited brand influence. Domestic cultural heritages such as Dunhuang grottoes and Longmen grottoes have achieved the upgrading of cultural tourism industry through digitalization and virtual-real integration display mode, effectively prolonging the stay time of tourists and improving the comprehensive income of scenic spots. Liaoning Province vigorously promotes the '15th Five-Year Plan' to promote the high-quality development of county economy and promote the quality and efficiency of county cultural tourism. Grasp the county tourism boom, deepen the "ticket root economy," and support the county with good cultural and tourism resources and great development potential to build a strong cultural and tourism county[1]. Therefore, the county cultural tourism industry urgently needs the empowerment of characteristic digital projects, the implementation of lightweight and low-cost stone carving virtual and real display projects, and the creation of differentiated digital cultural tourism experience, which can effectively activate the value of stone carving cultural tourism resources

in western Liaoning,stimulate the growth of local tourism economy,and help the high-quality upgrading of regional cultural tourism industry.

2. Construction of Core Technology System for Digital Protection of Cliff Inscriptions in Western Liaoning Empowered by AI

Combining the remaining characteristics,current damage status,and practical needs of the cliff inscriptions in western Liaoning,this paper integrates three core modules:multi-source data collection,AI intelligent processing,and cloud-based archive storage.It constructs a full-process intelligent and digital protection technology system encompassing "collection, processing,monitoring,and archiving",breaking through the limitations of traditional protection technologies and adapting to the complex mountainous terrain and grassroots implementation conditions in western Liaoning.

2.1. Multi-source Collaborative High-precision Field Data Acquisition Technology

The data acquisition of large-scale cliff carvings in the field has the characteristics of wide range,dangerous terrain and high accuracy requirements.There are obvious shortcomings in a single acquisition device.Three-dimensional laser scanning has high precision,but it is inefficient in the face of large-scale acquisition.UAV photography acquisition speed is fast,but the effect of close-range texture details is insufficient.Based on the existing state,the application research is positioned in the multi-source collaborative acquisition of 'UAV macro mapping+3D laser local fine scanning+field image supplement',and strives to take into account the integrity of the overall scene and the high precision of local details [2].

At the macro scene acquisition level,a six-rotor surveying drone equipped with a high-definition visible light camera is used.Based on the cliff terrain,a layered circular flight route is planned to fully cover and collect image data of the overall mountain environment and spatial distribution of the stone carvings.This quickly constructs an overall 3D scene model of the cliff,accurately records the spatial relationship between the stone carvings and the surrounding natural environment,and efficiently solves the problem of difficulty and low efficiency in modeling the overall scene of large stone carvings in mountainous areas.At the local detail acquisition level,for core statues,precious inscriptions,and key disease areas,a portable 3D laser scanner is used for close-range fine scanning to obtain high-precision point cloud data at the 0.1mm level.This fully preserves core details such as statue clothing lines,facial textures,text strokes,and minor damages of the stone carvings,compensating for the lack of precision in drone close-range texture acquisition.At the same time,the team takes high-definition texture photos of the stone carvings from multiple angles on site,and simultaneously organizes historical and cultural data such as the age,size,disease location,and historical background of the stone carvings,providing complete basic materials for AI model training and digital archive construction.

2.2. Data Intelligent Processing Technology based on Artificial Intelligence

The original point cloud data and image data collected in the field have problems such as noise redundancy,shadow occlusion,texture loss,and screen interference.Traditional manual processing is time-consuming and labor-intensive,and the accuracy is limited.The introduction of deep learning algorithm will realize the automation and intelligence of the whole process of data processing,and greatly improve the processing efficiency and data accuracy.

Firstly,the application of point cloud intelligent noise reduction and model lightweight optimization is realized.The original laser point cloud contains irrelevant noise points such as mountain weeds,branches,past tourists,and mountain gravel,and the manual screening and cleaning workload is extremely large.In this study,the convolutional neural network algorithm

is used to automatically identify, classify and eliminate invalid noise data. At the same time, the missing point cloud of the cliff occlusion area is intelligently completed to improve the overall structure of the three-dimensional model. Aiming at the massive high-precision model, a lightweight compression algorithm is adopted to reduce the storage volume of the model under the premise of completely retaining the core texture details of the stone carving, so as to adapt to the loading and operation requirements of the mobile terminal and lightweight equipment.

Secondly, complete the monitoring of automatic AI identification and classification of stone inscription diseases. By organizing stone inscription images captured in the field over many years, construct a dedicated image dataset covering four major types of diseases: weathering and spalling, water erosion and blurring, moss attachment, and stone cracks, and complete the specialized training of deep learning image recognition models. After inputting regularly collected on-site images of stone inscriptions into the model, the system can automatically locate disease areas, label disease types, measure damaged areas and damaged proportions, automatically generate annual disease comparative analysis reports, achieve dynamic quantitative monitoring of stone inscription damage, and provide precise data support for preventive protection.

Finally, AI texture virtual restoration is performed for incomplete statues. Aiming at the severely blurred and incomplete statue faces and inscriptions in Liaoxi stone carvings, based on the artistic style, carving system and texture features of the complete Liao and Jin stone carvings in the region, the training generates an adversarial network model, intelligently deduces the original texture structure of the incomplete area, and completes the virtual restoration at the digital level. The restoration is only applied to digital display, academic research and archives retention, and does not interfere with the cultural relics, effectively avoiding the ethical and technical risks of the restoration of cultural relics.

2.3. Establishment of Standardized Digital Archives Database

To achieve systematic, long-term, and secure management of stone inscription digital resources, this study has established an exclusive cloud-based digital resource database for the cliff inscriptions in western Liaoning. The database integrates and categorizes 3D models, high-definition images, disease monitoring data, and historical and cultural materials processed by AI intelligence. It is equipped with four core functional modules. First, the basic archive module centrally stores basic textual information such as inscription numbers, geographical locations, construction dates, dimensions, historical verification documents, and cultural relic grades, establishing a basic information ledger for stone inscriptions. Second, the 3D model module stores high-precision original acquisition models, lightweight display models, and AI virtual restoration models in layers, meeting the needs of different scenarios such as scientific research archiving, scenic spot display, and academic research. Third, the disease monitoring module archives images of inscription diseases, damage data, and annual comparative analysis reports year by year, enabling long-term tracking and tracing of the damage trend of stone inscriptions. Fourth, the permission management module sets hierarchical access permissions for cultural relic protection personnel, scientific researchers, and scenic spot operators, ensuring the security of the original high-precision data of cultural relics while enabling the open sharing of lightweight display resources, achieving the application goal of multi-scenario reuse of data.

3. Design and Application of the Virtual and Real Integration Display System for Cliff Inscriptions in Western Liaoning

Relying on the standardized digital archives resources, combined with the two application scenarios of indoor research and science popularization and outdoor scenic spot tour, the VR

immersive display system of the venue and the AR lightweight navigation applet of the mobile terminal are developed to build a multi-terminal,full-coverage,virtual and real linkage display system to break the pain points of single traditional display experience,weak interaction and limited time and space.

3.1. VR Immersive Display System for Venues

VR systems are primarily utilized in museums and indoor exhibition halls of scenic spots, adapting to research and educational settings as well as in-depth science popularization scenarios.They rely on complete three-dimensional models of cliff walls to create immersive digital experience spaces.The core functions of the system encompass three major components: First,panoramic real-life roaming of cliff walls.Users can immerse themselves in the original mountain environment of stone carvings by wearing ordinary commercial VR equipment,freely zooming in and out and closely observing the micrometer-level carving details of the stone carvings,thus compensating for the limitations of physical visits where one cannot approach steep cliff walls for observation.Second,interactive display of spatiotemporal restoration.Equipped with an AI virtual restoration model,it features a one-click switching function between "original intact state/current damaged state",allowing for an intuitive comparison of the ancient and modern appearances of stone carvings.Coupled with intelligent voice explanations and text annotations,it comprehensively interprets the legends of statues,Buddhist culture of the Liao and Jin dynasties,and the history of ethnic integration. Third,science popularization and research module.It incorporates animations of stone carving techniques,short videos on cultural relic protection,and educational materials on the history and culture of western Liaoning,providing interactive teaching content for research and educational activities in primary and secondary schools as well as for general cultural popularization,thereby enhancing the effect of cultural dissemination.The system has undergone lightweight processing,enabling it to operate without the need for high-end graphics workstations,significantly reducing the hardware costs for venue implementation.

3.2. Mobile AR Outdoor Guide Mini-program

Aiming at the lightweight and universal requirements of outdoor tours in scenic spots, WeChat AR navigation applet is developed. This technology can transform the traditional form of viewing cultural relics and listening to the narrator 's explanation into a new form of experience to appreciate multimedia creativity and operate virtual cultural relics, and improve the interest, interactivity and experience of museum exhibitions [3].Immersive experience is not derived from a single sensory stimulation, but a process from surface perception to deep identity. The effectiveness of this process depends on the precise implementation and coordination of design demands at all levels [4].Users do not need to download and install the APP, scan the code to enable, adapt to the full category of smart phones, greatly reducing the threshold for use. The core functions include : real intelligent recognition, mobile phone camera aiming at cliff stone carvings, AI algorithm quickly matching database resources, real-time superposition and restoration of complete statues and faded text ; multimodal cultural explanation, through the combination of voice, text and dynamic animation, explains the historical background, artistic value and folklore of stone carvings ; intelligent tour navigation, integrate the distribution points of Haitang Mountain and Tiecha Mountain stone carvings, intelligently plan the optimal tour route, and mark the key cultural relics protection points ; digital social communication, tourists can generate exclusive digital images of stone carvings after completing the tour, support online sharing and communication, and expand the influence of Liaoxi stone carving culture network.

In the process of multi-terminal virtual and real system development and integration, targeted solutions are formulated for the three core difficulties of field complex scene adaptation, mobile terminal operation jam and multi-device data synchronization. One is to solve the problem of

low accuracy of AR recognition under complex illumination in the field, expand the training data set of multi-period and multi-weather stone carving images such as sunny, cloudy, backlight, early morning and evening, optimize the feature matching algorithm of AI recognition model, improve the robustness of the model, and ensure stable recognition in complex environments such as weak light and strong light. The second is to solve the problem of loading the three-dimensional model of the mobile terminal. The hierarchical LOD model lightweight technology is used to realize the long-distance loading of the low-precision model, the close-range automatic switching of the high-definition detail model, and the cloud on-demand loading mode, reducing the local storage occupation of the mobile phone and improving the operation fluency. The third is to solve the problem of inconsistent data synchronization among multiple devices. The database sets up a unified standardized resource interface. The VR exhibition hall and AR applet call digital resources from the same source. After the database is updated, it is automatically synchronized to each terminal to ensure the unity of online and offline display content.

4. Conclusion

The AI digital preservation and virtual-real integration display system constructed in this article enables the cliff inscriptions in western Liaoning to break through the spatial and temporal limitations of physical remains. Based on the permanent preservation of cultural relic value, it integrates into public life in a new immersive and interactive form, providing a feasible practical path for the digital preservation, cultural revitalization, and collaborative development of the cultural tourism industry of northern wild stone cultural heritage. Digitalization and intelligence are the inevitable trend of long-term protection and dynamic inheritance of cultural heritage. With the continuous iteration of artificial intelligence, digital twins, and metaverse technology, the digital preservation and revitalization system of cliff inscriptions in western Liaoning will surely have broader development space.

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