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Computer-Aided Design AND APPLICATIONS

Digital Reconstruction and Display of Intangible Cultural Heritage Based on CAD Modeling and Reinforcement Learning

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Abstract. With the wave of globalization and the change of modern lifestyle, Intangible Cultural Heritage (ICH) is facing severe challenges of inheritance and protection. The traditional ways of mentoring and oral teaching have gradually failed to meet the needs of modern times. This article presents a digital reconstruction and display method of ICH based on computer-aided design (CAD) modelling and reinforcement learning (RL) technology. Firstly, this method uses CAD modelling technology to build a high-precision 3D model of intangible cultural objects to capture their complex shapes and detailed features. Then, the RL algorithm is introduced to optimize the CAD model to improve its accuracy and efficiency. Through this method, the digital reconstruction of intangible culture is realized, and it is displayed by technologies such as virtual reality and augmented reality, which provide strong support for the inheritance, protection, and innovation of intangible culture. The results show that the precision and efficiency of the CAD model have been significantly improved by introducing the RL algorithm for optimization. The optimized CAD model is superior to the original model in terms of detailed expression, geometric accuracy, and calculation efficiency.

Keywords: CAD Modeling; Reinforcement Learning; Intangible Heritage; Digital Reconstruction
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1 INTRODUCTION

ICH is the essence of human civilization and the imprint of history, which contains wisdom and affection from generation to generation. These heritages are spread all over the world, from oral art to social practice, festivals, handicrafts, and traditional knowledge, which deeply reflect the cultural uniqueness of a nation or region. CAD modelling technology plays an important role in the digitization of cultural Heritage due to its high precision and efficiency. Through CAD modelling, three-dimensional reconstruction of Cultural Heritage, such as cultural relics and architecture, can be achieved, providing basic data for subsequent digital display and virtual restoration. However, in the application process, CAD modelling also faces some challenges. Adane et al. [1] explored the challenges and opportunities faced by digitizing cultural Heritage based on CAD modelling and reinforcement learning technology. Through reinforcement learning, it can achieve intelligent analysis and optimization of digital models of cultural Heritage, improving the accuracy and usability of the models. In the digital restoration of cultural Heritage, reinforcement learning technology can automatically learn and optimize restoration strategies, improving restoration effectiveness. Meanwhile, reinforcement learning can also be applied to the digital display of cultural Heritage, providing users with a more authentic and vivid immersive experience. In terms of opportunities, it should fully utilize the advantages of CAD modelling and reinforcement learning technology to promote innovation and the development of cultural heritage digitization. With the rapid development of digital technology, Building Information Modeling (BIM) has become an indispensable tool in the construction industry. The interactivity, immersion, and interoperability of BIM technology provide a new perspective and solution for the protection, inheritance, and display of architectural cultural Heritage. Especially with the introduction of virtual reality (VR) and augmented reality (AR) technologies, the application scenarios and effects of BIM technology have been further enriched. Banfi [2] explored the evolution of interactivity, immersion, and interoperability in BIM, as well as the application of digital models, VR, and AR technologies in architectural cultural Heritage. The interactivity of BIM technology is mainly reflected in the interaction and sharing of information. Traditional 2D drawings cannot visually display the spatial relationships and structural details of buildings, while BIM technology enables participants to view, modify, and share building information in real time through 3D digital models. With the continuous advancement of technology, the interactivity of BIM is also gradually increasing. However, with the wave of globalization and the change in modern lifestyle, ICH is facing severe challenges of inheritance and protection. The traditional ways of mentoring and oral teaching have gradually failed to meet the needs of modern times, while intangible material carriers such as handicrafts and ancient buildings have also been damaged by years of erosion and environmental changes. In this context, digital technology has injected new vitality into the protection and inheritance of ICH. Through digital means, we can record and reproduce the intangible Heritage with high precision and multi-dimensions, break the time and space restrictions, and realize its permanent preservation and wide dissemination. Among them, CAD modelling technology plays an important role in the digital reconstruction of ICH with its powerful morphological description and visualization capabilities. Through CAD modelling, the intangible physical shape can be transformed into a digital geometric model, which not only retains its original shape and structure information but also supports further editing, analysis and optimization.

Historic buildings are an important component of urban culture, carrying rich historical information and cultural Heritage. However, over time, these buildings often face challenges in renovation and maintenance. In order to effectively manage and analyze the renovation process of historical buildings, 4D historical building information modelling and management technology has emerged. Bruno et al. [3] explored the role of 4D historical building information modelling and management in the analysis of building evolution and decay conditions during the renovation process. 4D historical building information modelling technology is based on three-dimensional building information modelling (BIM), adding a time dimension to form a four-dimensional building information model. This technology can comprehensively record the historical evolution of buildings, including changes in their structure, materials, decoration, and other aspects. Through 4D historical building information modelling, we can gain a deeper understanding of the evolution of buildings, providing strong support for renovation and maintenance work. With the rapid development of digital technology, virtual exhibition halls, as an innovative display method, are gradually receiving more and more attention and love from people. It not only breaks through the limitations of time and space, allowing viewers to enjoy exhibits anytime and anywhere, but also provides a more diverse and interactive display experience. Chen [4] introduced the design process of a virtual exhibition hall called "Cloud Weaving Dream" Chu Embroidery Virtual Exhibition Hall based on Blender and U3D. Chu embroidery is a unique genre in traditional Chinese embroidery art, known for its exquisite craftsmanship and rich cultural connotations. However, due to historical and practical limitations, the inheritance and development of Chu embroidery face many challenges. In order to promote the art of

Chu embroidery and attract more people to understand and appreciate it, we have designed a virtual exhibition hall called "Cloud Weaving Dream" for Chu embroidery. The exhibition hall aims to present a real, vivid, and interesting world of Chu embroidery art to the audience through virtual reality technology. It uses Blender software to create a three-dimensional model of the exhibits based on the characteristics and style of Chu embroidery. During the modelling process, attention is paid to the expression of details, striving to restore the true texture of Chu embroidery. Digital methods are playing an increasingly important role in the public outreach of cultural Heritage. The introduction of digital technology not only makes the protection, dissemination, and display of cultural Heritage more convenient and efficient but also provides the public with more diverse experiences. Farazis et al. [5] explored the application of digital methods in archaeology and cultural Heritage through case studies and analyzed their advantages and challenges in public outreach. Through VR technology, archaeologists can reconstruct three-dimensional models of ancient sites or cultural relics, allowing the public to experience ancient civilization firsthand. AR technology can overlay virtual information onto the real world, providing the public with a richer visiting experience. A digital museum is a platform for displaying and disseminating the collections of physical museums through digital means. Visitors can visit museums anytime and anywhere through the Internet or mobile devices to learn about rich cultural information. Digital museums not only break the limitations of time and space but also provide visitors with a more interactive and personalized visiting experience. There are still limitations in the use of CAD modelling technology alone in the digitization of ICH. Due to the complexity and diversity of ICH, it is sometimes difficult for CAD models to capture its dynamic characteristics and internal laws accurately. Therefore, RL technology is introduced into this study. RL is a machine learning method that learns strategies by interacting with the environment. It can find the optimal or nearly optimal behaviour strategy through trial and error without prior knowledge. In the digital reconstruction of ICH, RL technology can be used to optimize the CAD model, improve its accuracy and efficiency, and better restore and show the true face of ICH.

Heritage buildings are precious treasures of human history and culture, and their protection and restoration work is crucial. With the continuous advancement of technology, traditional architectural evaluation methods are no longer able to meet the needs of modern heritage protection. Therefore, combining CAD modelling and reinforcement learning technology to provide more accurate and efficient condition assessment for heritage buildings has become an important issue faced by decision-makers. Fino et al. [6] explored from the perspective of decision-makers how to use CAD modelling and reinforcement learning techniques for the scope definition review of heritage building condition assessment. Through high-precision scanning and measurement, detailed 3D models of heritage buildings can be constructed. This model not only helps decision-makers fully understand the geometric shape and structural characteristics of buildings but also provides rich data support for subsequent reinforcement learning algorithms. This article aims to explore the digital reconstruction and display method of ICH based on CAD modelling and RL technology. Through in-depth research and integrated application of these two technologies, we hope to break through the limitations of traditional digitalization of ICH, realize high-precision and high-efficiency digital reconstruction of ICH, and show it vividly with the help of advanced technologies such as virtual reality and augmented reality. This can not only provide new means and new ways for the protection and inheritance of intangible Heritage but also promote the integration and development of intangible Heritage and modern society and promote the common progress of cultural diversity and human civilization.

Theoretically, this article will deeply analyze the application principles and technical characteristics of CAD modelling and RL in the digitalization of ICH and discuss how to use these two technologies to capture and optimize the morphological information of ICH. In terms of application, this article will verify the feasibility and effectiveness of the proposed method through specific experiments and case analysis and discuss the application prospect and potential value of the intangible achievements of digital reconstruction in inheritance, education and tourism. Specifically, this study has the following innovations:

(1) This research combines CAD modelling technology with the RL algorithm and applies it to the digital reconstruction of intangible culture. CAD modelling ensures the high-precision geometric

description of intangible objects, while RL is used to optimize the model, which improves the efficiency and accuracy of the digitization process.

(2) This article puts forward a high-precision digital reconstruction method for the characteristics of ICH. Through careful data collection and accurate model construction, we can capture the subtle features and complex textures of intangible objects and ensure the high authenticity of digital results.

(3) In this study, the RL algorithm is introduced to optimize the CAD model intelligently. This optimization strategy can automatically adjust the parameters according to the real-time feedback of the model, thus improving the quality of the model without relying on prior knowledge and reducing the need for manual intervention.

This article focuses on the digital reconstruction and display of ICH based on CAD modelling and RL technology. Firstly, it introduces the research background and significance, then expounds on the relevant theoretical and technical basis, describes the proposed methodology in detail, and verifies the effectiveness of the method through experiments and analysis. Finally, it discusses the display and application prospects of digital achievements, forming a systematic and complete research structure.

2 RELATED WORKS

Cultural Heritage is a precious heritage of human history and civilization, which is of great significance for inheriting history and promoting culture. However, with time, cultural Heritage is facing a dual threat of natural and human factors, and its protection and inheritance work is urgent. In the field of cultural heritage protection, CAD modelling technology can achieve high-precision 3D reconstruction of Cultural Heritage, providing reliable data support for subsequent protection, restoration, and display work. Through CAD modelling, Gireesh [7] conducts detailed measurements and analyses of cultural Heritage to understand its structural characteristics, material properties, and historical changes, providing a basis for formulating scientific protection plans. Reinforcement learning is a machine learning technique that learns the optimal decision strategy through the interaction between intelligent agents and the environment. In the protection of cultural Heritage, reinforcement learning technology can be applied in multiple aspects, such as monitoring and early warning, restoration, and optimization. By building an intelligent monitoring and early warning system, we can monitor the status changes of cultural Heritage in real-time, identify potential safety hazards on time, and take corresponding protection measures. Meanwhile, reinforcement learning technology can also be applied to the optimization process of cultural heritage restoration, automatically adjusting restoration parameters and strategies through intelligent algorithms to improve restoration efficiency and quality. As an important carrier of human history and culture, cultural heritage sculpture art not only has profound artistic value but also carries rich historical information and cultural connotations. With the continuous advancement of digital technology, the application of CAD (Computer Aided Design) technology in the field of sculpture art is becoming increasingly widespread. CAD technology, with its efficient and precise characteristics, provides sculpture designers with new modelling and spatial expression methods, bringing new vitality to the creation and inheritance of cultural heritage sculpture art. CAD technology provides powerful styling support for sculpture designers through 3D modelling and digital design tools. Designers can use CAD software to draw three-dimensional models of sculptures accurately and perform morphological analysis, scale adjustment, and detail optimization operations. This not only greatly improves the efficiency and accuracy of design but also allows designers to explore the form and spatial expression of sculpture more freely [8].

New Year paintings are a unique form of traditional Chinese folk art, with rich colours and exquisite patterns, carrying profound cultural connotations. With the development of technology, the traditional way of drawing New Year paintings can no longer meet the needs of large-scale and efficient production. Therefore, developing an intelligent colour rendering system for New Year paintings based on a B/S (browser/server) structure is of great significance for protecting and inheriting the art of New Year paintings and improving production efficiency. Guo [9] provided a detailed introduction to the system's design and development process. In terms of functional requirements, the system needs to have functions such as intelligent recognition of New Year painting patterns, automatic colour matching, and adjustment of drawing parameters. In terms of performance requirements, the system needs to ensure fast response speed, high stability, and strong scalability. In terms of backend development, it uses Java, Spring and other technologies to achieve intelligent recognition of New Year painting patterns, automatic colour matching, and other drawing logic. In terms of database development, it uses relational database management systems such as MySQL to store and query data. It introduces the design and development process of an intelligent colour rendering system for New Year paintings based on the B/S structure. Through requirements analysis, system design, system implementation, system testing and optimization, we have successfully developed a powerful and stable intelligent colour rendering system for New Year paintings. Cultural Heritage is a treasure of human history and civilization, and its protection and inheritance are of great significance for the sustainable development of society. With the rapid development of digital technology, information management based on CAD modelling and reinforcement learning technology is playing an increasingly important role in cultural heritage protection. Korro et al. [10] explored how these technologies can promote sustainable protection of cultural Heritage and analyzed their potential and challenges in practical applications. CAD modelling technology provides an effective means for the digital protection of cultural Heritage. Through high-precision 3D scanning and modelling, the physical form of cultural Heritage can be transformed into digital models, thereby achieving accurate reproduction of its form, structure, and texture. This digital model not only helps to protect and store information about cultural Heritage but also provides convenient tools for subsequent restoration, display, and research. In order to protect and restore historical buildings more effectively, Historic Building Information Modeling (HBIM) based on CAD modelling and reinforcement learning technology has emerged. Lovell et al. [11] explored the application of HBIM based on CAD modelling and reinforcement learning technology in cultural Heritage and analyzed its advantages, challenges, and future development prospects. CAD modelling technology provides a foundation for information modelling of historical buildings. Through high-precision 3D scanning and digital modelling, detailed information such as the geometric shape, structural characteristics, and material texture of historical buildings can be obtained. These pieces of information not only provide data support for the restoration and protection of historical buildings but also provide a foundation for advanced technology applications such as reinforcement learning in the future. The application of HBIM based on CAD modelling and reinforcement learning technology in cultural Heritage has significant advantages. Firstly, HBIM can achieve high-precision modelling and information integration of historic buildings, providing comprehensive and accurate data support for protection and restoration work. Secondly, through the application of reinforcement learning technology, optimization and decision support can be achieved for the protection and restoration process of historical buildings, improving the effectiveness and efficiency of protection and restoration.

The combination of digital twin technology and reinforcement learning technology has brought new opportunities and challenges to the fields of museums and cultural Heritage. Luther et al. [12] explored how digital twins and reinforcement learning technologies can be utilized to empower the protection, inheritance, and display of museums and cultural Heritage. Digital twin technology refers to the construction of a virtual model that is highly consistent with the physical object through digital means, achieving digital replication and simulation of the physical object. Through digital twin technology, high-precision 3D scanning and digital archiving of cultural relics can be carried out, achieving permanent preservation and replication of cultural relics. Meanwhile, digital twin technology can also assist in cultural relic restoration work, improving restoration efficiency and accuracy. By utilizing reinforcement learning technology, an intelligent navigation system can be constructed to provide personalized navigation services for the audience. The system can recommend relevant cultural relics and exhibitions based on the interests and preferences of the audience, improving their visiting experience and satisfaction. Meanwhile, by monitoring and analyzing the status changes of cultural relics in real time, potential safety hazards can be identified on time and corresponding protection measures can be taken. This combination of applications can not only improve the protection efficiency and display effect of museums and cultural Heritage but also provide visitors with a better quality visiting experience. As a treasure of Chinese civilization, ancient ceramics carry rich historical and cultural information. However, due to the erosion of time and human factors, many precious ceramic artworks have suffered damage. In order to protect and inherit these priceless treasures, ceramic restoration technology has emerged. In recent years, with the rapid development of virtual reality (VR) technology, its application in ancient ceramic restoration has gradually emerged, bringing revolutionary changes to ceramic restoration work. Ming et al. [13] reviewed the system of virtual reality technology for ancient ceramic restoration, aiming to provide useful references for future ceramic restoration work. The traditional ancient ceramic restoration technology mainly relies on the manual skills and experience of restoration technicians, and the restoration process is cumbersome and time-consuming. Meanwhile, due to the particularity of ceramic materials, there are certain risks during the repair process, which may lead to further damage. Through virtual reality technology, restoration technicians can simulate the repair of ceramics in a virtual environment. This simulation repair process can help repair technicians predict and evaluate the repair effect in advance, reducing the risks in the actual repair process.

Cultural Heritage is a treasure of human civilization, carrying the value of history, culture, and art in material or intangible forms. However, with time, many cultural heritage sites are facing the risk of disappearing. In order to protect and inherit these precious legacies, we need innovative methods and tools. Heritage digital twins, as an emerging technology, provide new possibilities for the protection and inheritance of cultural Heritage. Niccolucci et al. [14] explored how to use Heritage digital twins to fill the data space of cultural Heritage, as well as their significance for cultural heritage protection and inheritance. Heritage Digital twins refer to high-precision modelling and information integration of Cultural Heritage through digital technology, creating a virtual model corresponding to physical and cultural Heritage. This virtual model not only has geometric accuracy but also integrates diverse information such as historical background, cultural connotations, material structure, etc. Through heritage digital twin technology, we can achieve comprehensive recording, analysis, and display of cultural Heritage. With the rapid development of digital technology, digital twin technology has gradually shown enormous potential in the field of cultural heritage protection. Digital twin refers to the virtual replication of physical entities through digital means and the simulation of their operation and change processes in a virtual environment. In museums, cultural Heritage building assets are digitally twin based on CAD modelling and reinforcement learning technology. Not only can it achieve high-precision restoration and display of cultural Heritage, but it can also optimize the operation and management of museums through simulation and analysis. Parsinejad et al. [15] explored the performance of cultural Heritage building assets based on CAD modelling and reinforcement learning technology in museums and analyzed their application prospects under the theme of digital twins in museums. Through CAD modelling, it is possible to accurately restore the geometric shape, structural characteristics, and material texture information of cultural heritage buildings. These digital models can be used not only for exhibition displays in museums but also for virtual restoration, simulation analysis, and other aspects. In museums, the application of CAD modelling technology can greatly improve the digitalization level of cultural Heritage building assets, laying the foundation for advanced technology applications such as reinforcement learning in the future. Digital cultural Heritage, as a perfect combination of digital technology and cultural heritage protection, provides us with a new perspective to explore, preserve, and inherit the treasures of human civilization. In this field, student participation is particularly important. They not only inject fresh blood and vitality into this field but also help us discover many forgotten and lost museums through their unique perspectives and creativity. Digital cultural Heritage refers to the process of utilizing digital technology to digitally preserve, showcase, and disseminate cultural Heritage. Through digital means, Schuster and Grainger [16] transform precious cultural relics, ancient books, artworks, etc., into digital form, achieving permanent preservation and unlimited replication. This not only helps to prevent cultural relics from disappearing due to natural factors or human destruction but also allows more people to have the opportunity to appreciate these treasures of human civilization.

Cultural Heritage is an important carrier of national history and culture, and its protection and inheritance are of great significance to the cultural security and sustainable development of a country. With the rapid development of information technology, Building Information Modeling (BIM) technology, as an emerging digital tool, provides new possibilities for the protection and inheritance of cultural Heritage. Solla et al. [17] proposed a BIM method for integrating geographic data to record and protect cultural Heritage. It aims to achieve a comprehensive and accurate recording of cultural Heritage through technological means, providing strong support for the protection and inheritance of cultural Heritage. Through BIM technology, it is possible to perform high-precision 3D scanning and digital modelling on cultural Heritage, obtaining detailed information on the geometric shape, material, structure, and other aspects of cultural Heritage. Meanwhile, BIM technology can also integrate diverse information such as geographical data, historical background, and cultural connotations of cultural Heritage, forming a complete database of cultural heritage information. This database can provide not only comprehensive and accurate data support for the protection of cultural Heritage but also rich information resources for the inheritance and display of cultural Heritage. Architectural Heritage is an important witness to human civilization and history, and its protection and inheritance are of great significance for the maintenance of cultural diversity. However, over time, architectural Heritage faces erosion from both natural and human factors, posing a serious threat to its structural integrity. In order to protect the structural integrity of architectural Heritage more effectively, the concept of digital twins has emerged. Vuoto et al. [18] explored the application of the concept of digital twins in the protection of structural integrity of architectural Heritage and analyzed its potential and challenges. Digital twin refers to the creation of a virtual model that corresponds to a physical object through digital technology. This virtual model not only has the geometric shape and structural characteristics of physical objects but also simulates their behaviour and performance in actual environments. The core of the concept of digital twins lies in achieving a seamless connection between the physical world and the virtual world, accurately predicting and optimizing the state and performance of physical objects through real-time data collection and analysis. Architectural Cultural Heritage is a witness to history and an important component of human civilization. With the development of digital technology, the use of CAD (computer-aided design) modelling technology to protect and inherit architectural and cultural Heritage has become a hot research topic. However, traditional CAD modelling methods face many challenges when dealing with complex architectural and cultural Heritage, such as structural complexity, polymorphism, and lack of sufficient training data. To address these challenges, Xie [19] proposed a CAD modelling technology for architectural cultural heritage projects based on reinforcement learning extended graphs and polymorphic models. In the CAD modelling of architectural and cultural Heritage, reinforcement learning can automatically adjust modelling parameters and strategies through the exploration and learning of the environment by intelligent agents, thereby improving the accuracy and efficiency of modelling. Extended graph is a graphical structure used to represent state and action transition relationships, which can be applied in reinforcement learning to guide the learning of intelligent agents.

3 INTRODUCTION OF THEORETICAL BASIS AND TECHNOLOGY

3.1 CAD Modeling Technology and Its Application Advantages in ICH

Based on the above research results, we can see that digital technologies such as CAD modelling technology, RL algorithms, and VR/AR play an important role in the protection, inheritance, and innovation of intangible culture. However, the existing research still has some limitations. For example, in CAD modelling, it is still a challenge to model complex non-legacy objects accurately. In terms of RL optimization, how to design effective reward functions and strategies still needs further exploration. In terms of digital display, how to realize a more natural and intelligent interactive experience is also an important direction for future research.

Given the limitations of existing research, this article puts forward a digital reconstruction and display method of intangible culture based on CAD modelling and RL technology. By introducing advanced CAD modelling technology to capture the morphological characteristics of intangible culture accurately and combining the RL algorithm to intelligently optimize the CAD model, the accuracy and efficiency of the model can be improved. At the same time, this article will also explore the use of VR/AR and other advanced technologies for vivid digital display in order to provide new means and ways for the protection and inheritance of intangible culture. CAD modelling technology, as a core technology in modern design and manufacturing, has been deeply integrated into the creative, analytical, and optimization processes of various products [15]. In terms of the digital reconstruction of ICH, CAD modelling technology, with its unique advantages, provides strong support for the protection and inheritance of this precious Heritage.

This technology is based on mathematical principles, accurately describing the geometric form and properties of objects. By combining elements such as points, lines, and surfaces and defining topological relationships, a lifelike 3D model is constructed. In the process of digitizing ICH, CAD modelling technology can capture subtle texture features, ensuring the authenticity and precision of digital models, which is crucial for maintaining the original appearance of ICH.

The flexibility of CAD modelling allows designers to easily edit and modify models, whether it is scaling, rotating, or translating, and can present real-time effects, providing unlimited possibilities for the innovative display of ICH. Meanwhile, its excellent data compatibility enables CAD models to seamlessly integrate across multiple platforms and application software, greatly promoting the sharing and dissemination of digital achievements in ICH.

3.2 RL Technology and Its Potential for Digitalization of ICH

RL is a machine learning method that learns decisions through dynamic interaction with the environment and has shown great potential in the digital reconstruction of ICH culture. The core lies in the intelligent agent learning how to choose the optimal action in different states to maximize long-term returns through continuous trial and error.

In the digital context of ICH culture, RL technology can be applied to optimize the accuracy and efficiency of CAD models. By intelligently adjusting model parameters or geometric structures, the RL algorithm can help CAD systems capture the features of ICH objects more accurately while reducing computational complexity and improving processing efficiency.

RL also has significant advantages in automated decision-making. In the process of digital reconstruction, key decision points such as scanning device selection and parameter settings can be automated and intelligently processed through RL algorithms, greatly improving the efficiency and accuracy of digital processes.

3.3 The Integration and Innovation of CAD Modeling and RL

The combination of CAD modelling technology and RL opens up a new way for the digital reconstruction of ICH culture. This fusion not only improves the degree of automation and reduces the need for manual intervention but also improves the quality of the model through intelligent optimization. More importantly, this combination has the potential for cross-domain application and can provide new solutions for the protection of cultural relics, art design, and other fields.

When realizing this fusion, we need to pay attention to the compatibility of data formats, the integration method of algorithms, and the friendliness of the user interface. Ensure that the CAD system and RL algorithm can exchange data smoothly and work together, and provide users with an intuitive and easy-to-use operation experience.

4 METHODOLOGY

In this article, we propose a methodology for the digital reconstruction of ICH culture based on CAD modelling and RL technology. The methodology aims to capture the morphological characteristics of ICH culture through high-precision 3D scanning and CAD modelling technology. The RL algorithm is used to intelligently optimize the CAD model to improve the accuracy and efficiency of the model. The specific steps and key technologies of this methodology will be elaborated in detail below.

4.1 3D Scanning and Data Preprocessing

First of all, we use high-precision 3D scanning equipment to scan ICH cultural objects and obtain 3D point cloud data on their surfaces. The selection of 3D scanning equipment should be determined according to the characteristics of ICH objects and scanning requirements so as to ensure that the obtained point cloud data has sufficient accuracy and resolution. The data acquisition process based on a neural network is shown in Figure 1.

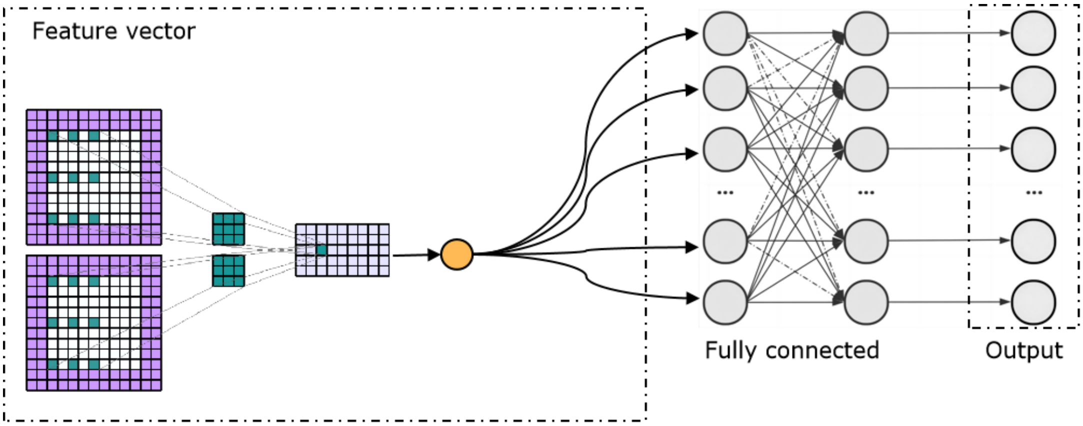

Figure 1: Data acquisition process.

The scanned point cloud data usually contains a lot of noise and redundant information, so data preprocessing is needed to improve data quality. The main steps of data preprocessing include denoising, filtering, registration, and simplification. Among them, denoising aims at eliminating random noise in point cloud data; Filtering can smooth the data and reduce the errors in the scanning process; The matching criterion is to align the point cloud data from multiple scanning perspectives to the same coordinate system; Simplification is to reduce the complexity of data by reducing the number of points.

For the denoising process, the statistical filtering method is adopted, and the neighbourhood information of each point in the point cloud is used to judge, and the points deviating from the normal range are eliminated:

$$d_i = \frac{1}{N}\sum_{j=1}^{N}\left\|p_i - p_{ij}\right\| \tag{1}$$

Where d_i represents the average distance from point p_i to N points in its neighborhood, and p_{ij} represents the j neighborhood point of point p_i. Setting an appropriate threshold d_i can be compared with the threshold so as to judge whether the point p_i is a noise point.

When point cloud data from multiple scanning perspectives are aligned to the same coordinate system, an iterative nearest point algorithm can be used for registration. The transformation matrix T in the registration process can be solved by minimizing the following objective function:

$$E(T) = \frac{1}{N_p}\sum_{i=1}^{N_p}\left\|p_i - Tq_i\right\|^2 \tag{2}$$

Where p_i and q_i respectively represent corresponding points in two point clouds, and N_p is the number of corresponding points.

In the process of RL, the agent interacts with the environment, and the state transition probability can be expressed as:

$$P^{a}_{ss'} = \Pr\ s_{t+1} = s' \middle| st = s, at = a \tag{3}$$

Where st and s_{t+1} are the current and next states, respectively, and where is the currently executed action?

4.2 CAD Modeling and Morphological Analysis

After data preprocessing, the point cloud data is reconstructed by CAD modelling software, and the 3D CAD model of the ICH cultural object is generated. The process of CAD modelling mainly includes surface fitting, boundary extraction, and model construction. Surface fitting aims to approximate the surface shape in point cloud data by mathematical methods; boundary extraction is used to determine the boundary contour of the surface; model building is used to build a complete 3D model according to the surface and boundary information. The modelling optimization process based on DRL is shown in Figure 2.

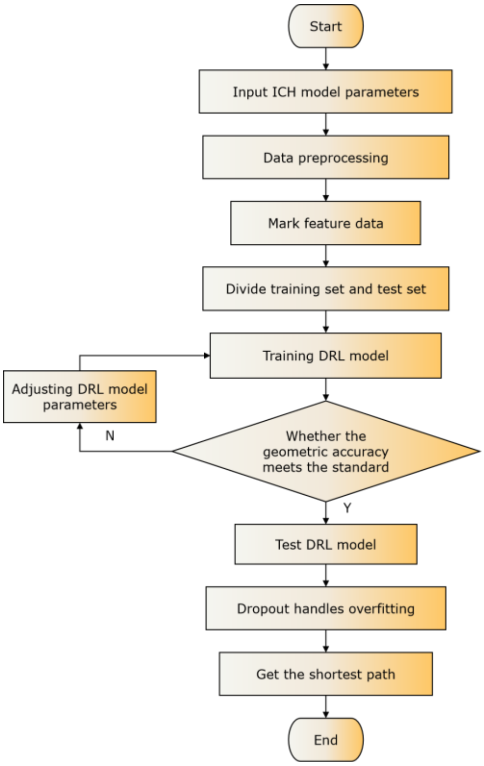

Figure 2: DRL-based modeling optimization process.

In the process of CAD modelling, a series of mathematical formulas are used to describe the process of surface fitting and model construction. For the surface fitting process, the least square method is used to approximate the surface in point cloud data:

$$E = \sum_{i=1}^{M} \left\| f(x_i, y_i) - z_i \right\|^2 \tag{4}$$

Where E represents a fitting error, $f(x, y)$ represents a fitting surface function, and (x_i, y_i, z_i) represents points in point cloud data. By minimizing the fitting error E, the optimal surface function $f(x, y)$ that approximates point cloud data can be obtained.

Scanning errors are inevitable in the process of 3D scanning of ICH culture. This error can be estimated by the following formula:

$$\varepsilon = \sqrt{\frac{\sum_{i=1}^{n} \left(x_i - \hat{x}_i\right)^2 + \left(y_i - \hat{y}_i\right)^2 + \left(z_i - \hat{z}_i\right)^2}{n}} \tag{5}$$

Where (x_i, y_i, z_i) are the actual coordinates of scanning points, $(\hat{x}_i, \hat{y}_i, \hat{z}_i)$ are the measured coordinates of scanning points, and n are the total number of scanning points? This formula is used to assess the accuracy of scanned data.

4.3 Model Optimization Based on RL

After completing the preliminary CAD modelling, in order to ensure that the model reaches the optimal state in terms of accuracy and computational efficiency, the RL algorithm is further introduced to optimize the model. Traditional CAD model optimization methods usually rely on manual adjustment and empirical rules, which are time-consuming and make it difficult to ensure the global optimal solution. As an adaptive and data-driven optimization technology, RL can automatically explore and optimize the parameters and structure of CAD models through interactive learning between agents and the environment. Specifically, the RL algorithm is applied to parameter adjustment and geometric structure optimization, aiming at finding the best balance between model accuracy and computational efficiency through iterative optimization. In this process, neural network structure plays a core role, and its design and training are very important for the optimization effect. As shown in Figure 3, the neural network structure adopted in this study combines the characteristics of CAD modelling and the requirements of RL and can effectively support feature extraction and decision-making in the process of model optimization. With this neural network structure, the intelligent optimization of the CAD model is studied and realized, which provides strong support for the digital reconstruction of ICH culture.

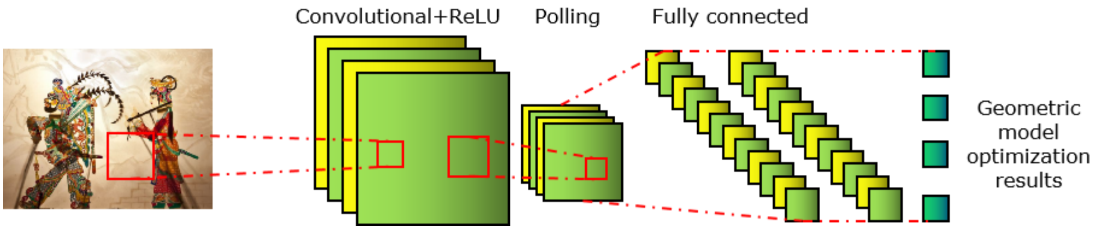

Figure 3: Neural network structure for model optimization.

In the aspect of parameter adjustment, we define an RL model in which the agent is the parameter adjuster, and the environment is the quality evaluator of the CAD model. At each time step, the parameter adjuster selects an action to execute according to the parameters of the current CAD model, and then the quality evaluator assesses the CAD model after executing the action and gives a reward signal. The goal of the parameter adjuster is to find a strategy through learning to maximize the cumulative reward obtained in the long-term interaction process. The specific formula is as follows:

$$Q(s,a) \leftarrow Q(s,a) + a\left[r + \gamma \max_{a'}(s',a') - Q(s,a)\right] \tag{6}$$

Where $Q(s,a)$ represents the cost function of performing the action a in the state s, a represents the learning rate, r represents the reward obtained, γ represents the discount factor, and s' represents the new state after performing the action a. By constantly updating the value function $Q(s,a)$, the parameter adjuster can learn an optimal strategy to adjust the parameters of the CAD model.

In the aspect of geometric structure optimization, we adopt a similar RL model to optimize the geometric structure of the CAD model. Specifically, we define a quality evaluator whose agent is a geometric structure optimizer and whose environment is a CAD model. Geometric structure optimizers can improve the structural quality of CAD models by learning to choose appropriate geometric transformation actions, thus improving the accuracy and expressive ability of the model. The specific formula is as follows:

$$\pi(a|s) = \frac{e^{Q(s,a)}}{\sum_{a'} e^{Q(s,a')}} \tag{7}$$

Where $\pi(a|s)$ represents the strategy function of performing the action a in the state s, and $Q(s,a)$ represents the cost function. By adopting a softmax strategy to select actions, the geometric structure optimizer can gradually converge to the optimal strategy while ensuring exploration.

In RL, the value function is used to assess the long-term value of a state or state-action pair. For the state value function $V(s)$, its update formula can be expressed as:

$$V(s) \leftarrow (1-\alpha)V(s) + \alpha\left[r + \gamma V(s')\right] \tag{8}$$

Where a is the learning rate, γ what is the discount factor, and s' what is the next state?

When simplifying the CAD model, it is necessary to control the error between the simplified model and the original model. The simplification error can be calculated by the following formula:

$$\delta = \frac{1}{N_s}\sum_{i=1}^{N_s}\left\|P_i - \hat{P}_i\right\| \tag{9}$$

Where P_i is the point on the original model, $\hat{P}_i$ is the approximate position of the corresponding point on the simplified model, and N_s is the number of sampling points.

5 EXPERIMENT AND ANALYSIS

In order to verify the validity of the methodology proposed in this article, a series of experiments and analyses were carried out in this study. Firstly, several representative ICH cultural objects are selected for 3D scanning and CAD modelling. Then, the parameters of the CAD model are adjusted, and the geometric structure is optimized by the RL algorithm. Finally, the optimized CAD model is compared and analyzed with the original model. In the hardware aspect, the experiment adopts high-precision 3D scanning equipment, which has high resolution, the ability to capture details, and the ability to accurately obtain the 3D morphological data of ICH cultural objects. In order to process and analyze these data, this study is equipped with a high-performance computer system, including a fast processor, a large memory and an efficient graphics processing unit. In terms of software, professional CAD modelling software is developed, which provides rich tools and functions and supports the complete modelling process from point cloud data to 3D models. In addition, in order to optimize the model, the RL algorithm is introduced, and the development and deployment of the algorithm are realized through the corresponding programming language and framework. The whole experimental environment has been carefully designed and configured in software and hardware to ensure the accuracy, efficiency and stability of the digital reconstruction process.

Figure 4 shows the geometric accuracy simulation results of different methods. Compared with other methods, the geometric accuracy of the optimized CAD model has been significantly improved. This is mainly due to the effective application of the RL algorithm in model parameter adjustment. Through the interactive learning between the agent and environment, the RL algorithm can find the optimal parameter configuration, which makes the CAD model better fit the geometric characteristics of the original ICH cultural object.

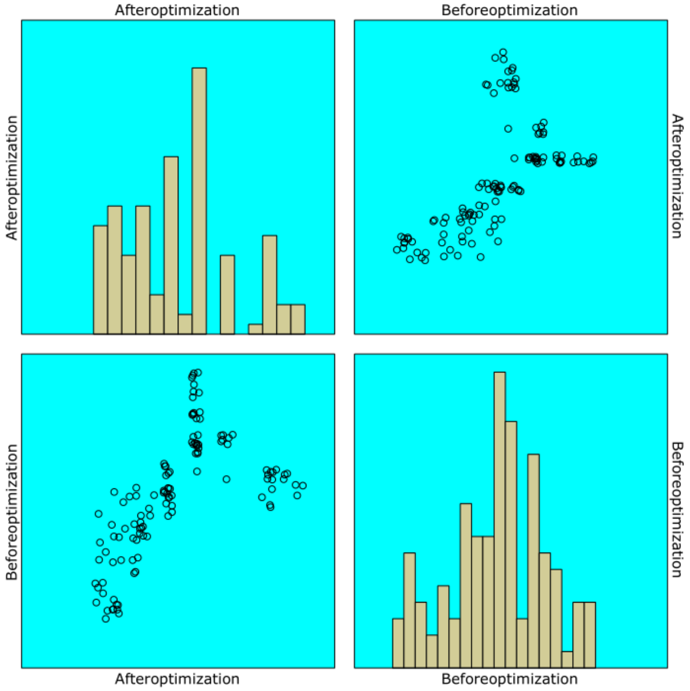

Figure 4: Geometric accuracy simulation of different methods.

Figure 5 shows the simulation results of the modelling efficiency of different methods. Similarly, the optimized CAD model also shows obvious advantages in modelling efficiency. This is mainly due to the optimization of model geometry by the RL algorithm. By choosing appropriate geometric transformation actions, the RL algorithm can improve the structural quality of the CAD model and reduce unnecessary calculation and storage overhead. This improvement in efficiency is particularly important for the large-scale and complex digital reconstruction project of ICH culture because it can significantly reduce the time cost and the demand for computing resources.

By combining CAD modelling technology with RL, high-precision and high-efficiency digital reconstruction of ICH culture can be realized. The optimized CAD model has significantly improved the geometric accuracy and calculation efficiency.

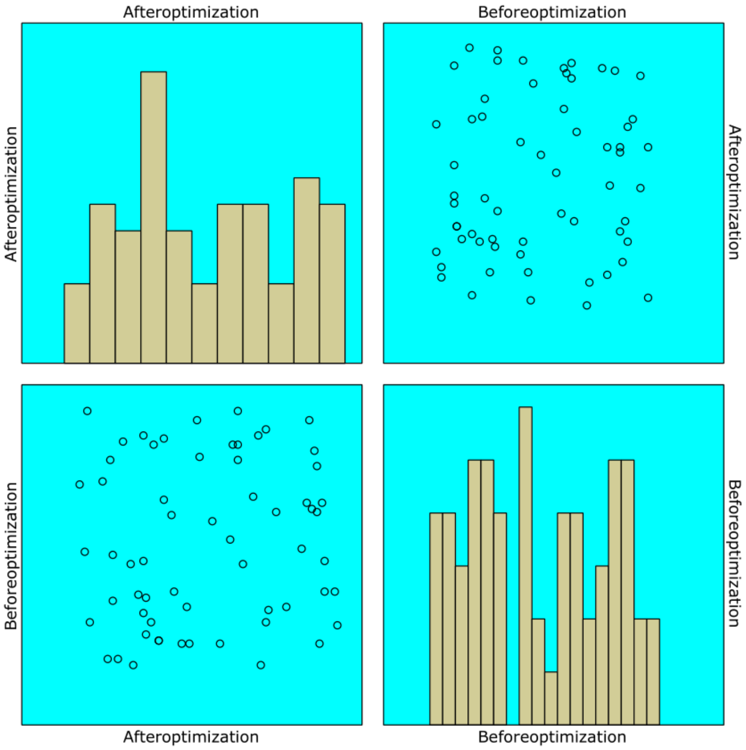

Figure 5: Modeling efficiency simulation of different methods.

6 DISPLAY AND APPLICATION

Figure 6 and Figure 7 shows the modelling effect of ICH before and after optimization, respectively. By comparing these two figures, it can be clearly seen that the modelling effect after optimization has been significantly improved, and the details are richer and finer.

Figure 6: Modeling effect before optimization.

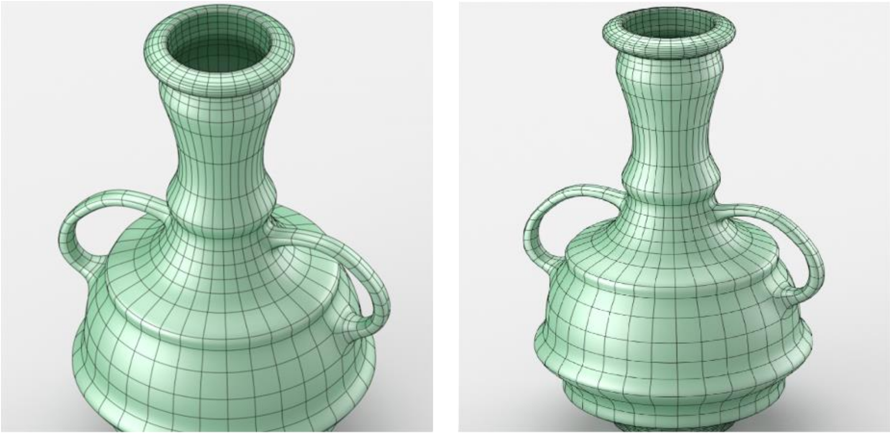

Figure 7: Optimized modelling effect.

In the CAD modelling process, this article uses techniques such as surface fitting and boundary extraction to reconstruct the geometric form of ICH objects accurately. By introducing the RL algorithm, the parameters and geometric structure of the CAD model were intelligently optimized. The RL algorithm can automatically adjust the model parameters and select the optimal geometric transformation action based on the current state and quality evaluation results of the model, thereby gradually improving the accuracy and efficiency of the model. This optimization process is iterative, and through continuous trial and error and learning, the RL algorithm can find an optimal strategy to achieve the optimal CAD model in terms of detail representation, geometric accuracy, and computational efficiency.

7 CONCLUSION AND OUTLOOK

This article explores the methodology of digital reconstruction of ICH culture based on CAD modelling and RL technology and verifies its effectiveness and superiority through experiments. This method not only provides a new perspective and means for the protection and inheritance of ICH culture but also expands new space for the application of digital technology in the field of traditional culture.

Through high-precision 3D scanning and CAD modelling technology, it is possible to capture the subtle morphological features of ICH culture and achieve precise digital expression of it. The introduction of the RL algorithm provides powerful, intelligent support for the optimization of CAD models. The results show that the optimized CAD model has significantly improved geometric accuracy and computational efficiency, with richer detail expression, and can better restore the original charm and spiritual connotation of ICH culture. This method can be widely applied to the digital reconstruction of various types of ICH cultural objects, such as traditional handicrafts, ancient architecture, ethnic costumes, etc.

In summary, the digital reconstruction methodology of ICH culture based on CAD modelling and RL technology proposed in this article provides new ideas and means for the protection and inheritance of ICH culture and also provides new opportunities for the application of digital technology in the field of traditional culture. In the future, we will continue to explore and improve this method, contributing more wisdom and strength to the digital innovation and development of ICH culture.

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