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Current Status of Application of Virtual Restoration Technology in Cultural Heritage Conservation

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Abstract: *With the wide application of computers and Internet systems and the deepening of the idea of cultural heritage conservation, virtual restoration technology has been extensively used in the field of cultural heritage, but there are still many problems. This thesis summarizes the current application cases of virtual restoration in the establishment of digital scenic spots, repair of damaged cultural relics, and color restoration of faded and discolored areas on the basis of the basic concept of virtual restoration technology. In addition, it outlines that the status quo of virtual restoration is characterized by preference for theoretical research, technical failure of meeting the requirements of virtual restoration of cultural heritage, and lack of the combination of various virtual restoration technologies. It also proposes that future research / work should concentrate on establishing a cultural heritage database, improving the software and hardware design of virtual restoration, establishing corresponding principles and standards, and cultivating professional talents so as to provide suggestions for the development of virtual restoration technology in cultural heritage conservation.*

Keywords: *virtual restoration; cultural heritage; conservation*

1. Introduction

Cultural heritage, as a witness to the development of human civilization, has rich historical, artistic and scientific value. At present, with the development of tourism, the improvement of national quality, and the in-depth study of cultural heritage protection theory, tourists, the public, and practitioners of cultural heritage all set higher standards for the protection and inheritance of cultural heritage. It has become a tricky problem facing us to make use of science and technology in the new era to bring cultural heritage into full play[1].

With the development of computer technology and the spread of the “Internet Plus”, the use of virtual restoration technology to survey, map, restore and monitor cultural heritage has become an indispensable part of cultural heritage conservation. Virtual restoration excels at extracting information and processing data without destroying the essence of cultural heritage. Digital image processing technology, 3D model restoration technology, and a variety of virtual restoration technology like virtual simulation technology can also provide customized solutions for different kinds of cultural heritage. They have the functions that cannot be achieved by traditional restoration in terms of data acquisition, image processing, auxiliary copying, image restoration, virtual display, and color management.

This paper systematically compares the current application examples of virtual restoration technologies in the field of cultural heritage, such as digital image processing technology, 3D model restoration technology, and virtual simulation technology on the basis of the conceptual interpretation of virtual restoration technology [2] , It also systematically summarizes the current situation of the application of virtual restoration technology, and then puts forward corresponding suggestions to tackle existing problems, which contributes to its development in the field of cultural heritage as well as the conservation and inheritance of cultural heritage in China.

2. Overview of virtual restoration technology

Virtual restoration technology refers to the restoration technology which draws upon both 2D and

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3D software of computers to establish a virtual space and obtain and store data on cultural relics relying on digital means while establishing a corresponding virtual model [3] . Virtual restoration is based on the research and judgment of the target, the overall picture of data from cultural relics and its geographical environment. It is currently divided into four major directions: digital image processing technology, 3D model restoration technology, virtual simulation technology, and computer software restoration.

2.1 Digital image processing technology

Digital image processing technology is fundamentally designed to acquire a better visual effect by improving image quality. It mainly holds 2D data as information source and processes images and signals on computers [4] .In cultural heritage conservation and restoration, it is applied to acquire and store image data by digital technology, improve image quality through image enhancement technique [5] , and maximize the known information. After identifying logical relationships among various parts of image and performing pixel matching and duplication, it restores unknown areas. Based on different "restoration" methods, digital image processing technology can be divided into two groups: non-texture synthesis-based image restoration technology and texture synthesis-based image restoration technology [6] .

2.1.1 Non-texture synthesis-based image restoration technology

The non-texture based synthetic image restoration technology in this thesis is mainly based on the PDE (Partial Differential Equations) restoration model and the variational restoration model. The principle of the former is to use the computer to establish a mathematical equation also known as PDE at the boundary of the damaged part of the artifact, and then make the image or other information we get gradually diffuse along the normal of the iso-illumination line to the damaged part, so as to restore the image[7] . The latter realizes restoration by building two models, a priori model and a data model, which solve the extremum of the fonctionelle [8] . The two can deduce each other equivalently through the variational principle.

The non-texture synthesis-based image restoration technique is less suitable to be applied in restoring cultural relics with large damages or relatively complex colors of image texture because of the excessive blurring effect during the restoration process. It is universally applied to restore small-scale damaged areas such as scratches and spots [9] . Owing to the complex processing, it is less used than texture synthesis-based image restoration.

2.1.2 Texture synthesis-based image restoration techniques

The texture synthesis-based restoration method is also a method used to complete the repair of broken areas of cultural relics, which achieves virtual synthesis of image textures by using the singularity, repetition, and regularity of image texture. It is mainly divided into image decomposition-based restoration techniques and sample-based texture synthesis techniques [10] The first approach decomposes the overall image from two categories, texture and structure. Each category completes the restoration separately. The first category analyzes overall texture and fills it after the synthesis while the second category needs to first repair algorithms and then synthesizes the two parts [11] . The second method is mainly divided into three parts: synthesis adoption, feature matching and constraint synthesis. The principle of restoration is to find the pixel in the intact area which is most similar to that in the broken area and make the image complete by copying the module with the best content and outer edge to the area in need of repair. Different from the non-texture synthesis-based image restoration technique, this method is more suitable for images with large damaged areas and rich textures.

2.1.3 Image restoration technology based on other principles

The restoration is achieved by means of digital image restoration, whether it is non-texture-based synthesis or texture-based synthesis. The idea of cycle dominates two methods of restoring cultural property, where the more iterations are, the better the restoration is[12] . Nevertheless, the large number of iterations overburden computers. As the number of iterations increases, the algorithm runs more slowly, thus forcing researchers to find more effective and faster restoration methods. Fast Marching Method (FMM) was an image restoration method proposed by Telea in 2004. This method restores images entirely by starting from the damaged edge of the image of cultural property to be restored and advances to the inside by fast marching. Meanwhile, it repairs damaged pixels during the process [13]. This algorithm improves the speed of texture synthesis technology. Besides, there is another major

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progress based on the Navier-Stokes equation image algorithm, which can fill the area to be repaired with information. If there is an anisotropic smooth image outside that area, it can remove the noise and maintain the edge information [14] .

2.2 3D model restoration technology

The application principle of 3D model restoration technology is laser ranging. After the laser scanning, the entire external shape, internal structure, surface color, spatial location, and other important data of objects are extracted, which helps establish a preliminary data model of cultural heritage [15] .Specifically, after using the laser scanner to emit laser lines to the surface of cultural relics, researchers can use it to record reflection information and get the 3D data of the relative position of the point cloud on the surface of cultural relics. Based on such data, a geometric point cloud array can be created on the surface of cultural relics, and thus a more accurate model appears. Likewise, 3D scanning can also obtain the surface color of the cultural relics, which needs to be done through the material mapping method, that is, the color is obtained by laser emission after the surface of the established model is attached to a material map of the corresponding color [15] . 3D scanners can be divided into two kinds according to the contact with objects: contact 3D scanners and non-contact 3D scanner. Due to the indestructibility of cultural relics, non-contact 3D scanners are widely used in the area of cultural heritage [15] .

The application principle of the 3D laser scanning technology in the virtual restoration of cultural property is to establish a model based on high-precision 3D point cloud data of cultural property, through which the size of the missing parts of the cultural relics is predicted to provide a reference for the conservation of cultural heritage [16]. At the same time, through the establishment of 3D model and 3D point cloud data, the permanent preservation of cultural heritage information can be implemented and archives of cultural heritage conservation can also be established, which provides solid data for cultural heritage conservation [17] .

2.3 Virtual Simulation Technology

Virtual Simulation Technology is a high tech which unifies computer graphics, human-computer interaction technology, sensing technology, and artificial intelligence. In essence, it uses a virtual system to simulate the real world. It offers users an immersive virtual experience environment with powerful computer graphics processing functions and visualization technology [18].

"The significance of virtual simulation technology for cultural heritage exists primarily in two aspects, conservation and publicity. This technology simulates the condition of cultural heritage after restoration in a virtual way, thus providing certain technical support and guidance in the restoring process. Moreover, it can also plan and arrange cultural heritage conservation works in an orderly manner to ensure the timeliness and effectiveness of conservation works [19].

Virtual simulation technology is usually used with digital image restoration technology and 3D laser scanning technology to establish digital simulation scenic spots. On the one hand, it can increase the interactivity between cultural relics and visitors and improve a sense of presence of visitors through multi-angle perception. On the other hand, it can relieve the pressure of scenic spots caused by a large number of tourists, which helps avoid damage to cultural heritage[20] .

2.4 Computer software repair

With the development of computer technology and the upgrading of image processing software, computer software such as MATLAB, PHOTOIMPACT, and PHOTOSHOP can also be applied in virtual restoration of cultural heritage [21]. MATLAB Matrix Lab has the functions of numerical analysis, engineering and scientific drawing, etc.; PHOTOIMPACT plays the roles of fast film retouching and baseline adjustment. PHOTOSHOP, the most widely used computer software in virtual restoration, can conduct image editing and image pixel replication and restore the original information of cultural heritage to the greatest extent without destroying it. It successfully solved many problems that could not be solved in image restoration of cultural heritage in the past. More importantly, for some faded and discolored cultural relics, it can make color correction and restore their original color.

PHOTOSHOP also plays a great role in the simulation of line drawing elements. After screening and studying the style of lines in the area to be repaired, it creates simulation brushes in different ways according to different application areas and requirements, generates a brush database so as to make the

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match more convenient for the complete restoration of lines, and then fulfils image fusion for targets in the later stage of data processing. The complete restoration image emerges after researchers make some refined adjustments to the matched line drawings by virtue of their professionalism and comprehension. This method not only improves the efficiency of restoration, but also avoids the irreversibility of traditional restoration [22].

3. Current status of virtual restoration technology in cultural heritage conservation

At present, the application of virtual restoration technology in cultural heritage conservation has taken shape. On the one hand, the theoretical research on "technology + Internet" is going deeper and deeper, and more technical means become more suitable for cultural heritage conservation after being improved. On the other hand, the practical application of virtual restoration technology in cultural heritage conservation is also very extensive. The development of computer hardware and software provides the necessary material support for virtual restoration technology, and has achieved certain results.

3.1 Application cases

3.1.1 Establishment of digital scenic spot

Mogao Caves, the first of the four major grottoes in China and the world's largest and best-preserved sacred site of Buddhist art, is a famous cultural heritage in China. It has been the first to use virtual restoration techniques and establish a digital scenic spot in conservation [23]. First, a textual database is established: the comprehensive collection of Dunhuang literature and related research results around the world to systematically establish a electronic archive, and second, information data are collected and processed: a variety of techniques such as close-up photography, aerial photography, and 3D laser scanning are applied to obtain various data on the sculptures and murals inside the Mogao Caves as well as the external topography, landforms, and environment. Models like 3D visual model, digital opposite model, and orthographic impact model are subsequently constructed. Third, 3D image information is recovered and reconstructed: virtual reality technology is used to create a fully immersive interactive environment between the virtual and the real, which is a 3D visual model that can be used not only for demonstrations and visits, but also for the study of the entire Mogao Caves cultural heritage, as well as the recovery of image information and even reconstruction [24] .

The Big Buddha in Hong Kong, the largest open-air bronze seated statue in the world today, uses a three-in-three-out plan layout, whose complex architectural structure poses high requirements for repair. When it comes to the conservation of the Buddha with 3D information system and virtual simulation technology, it is necessary to use a variety of measurement means like measuring instruments, manual work, photography, laser scanning and so on, in order to ensure the acquisition of accurate and complete information about the architectural heritage. Then, by virtue of the accurate data, 3D models of each component are established and preserved, thus a 3D model of the overall building digital archive is formed, which provides a new idea for the study of the reproduction of ancient architectural construction techniques and technologies [19] .

The "Virtual Forbidden City" is the first virtual world of China that presents important historical and cultural heritage on the Internet. This conservation project is designed to closely integrate Chinese history and culture [25] , and to capture the movements of live characters on site in a dynamic stimulation, creating a 3D vision on the information collection with high resolution and fine 3D modeling technology to reproduce the royal virtual palace complex. It not only can guide the conservation of Forbidden City buildings, but also allows visitors to interact with pre-defined characters and experience ancient life in activities, thus increasing the interactivity between cultural heritage and visitors.

3.1.2 The repair of broken artifacts

Professor Mingquan Zhou of Northwestern University comprehensively combines various related disciplines, namely computer geometry, image processing technology, and vision and pattern recognition technology [26]. He first digitizes the damaged cultural relics, labels the various characteristics of the surface of the damaged fragments in the traditional way, then scans the fragments with a 3D scanner to obtain the point cloud data of the fragment curves, and analyzes the curve characteristics, so as to establish a model for the recovery of curved fragments of cultural relics [27] . Then he judges the matching relationship based on the results of the similarity calculation

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of the curve direction angle construction feature vector, and finally completes the automatic splicing of the fractured surface of the broken objects by techniques like contour surface matching, shape matching, coarse matching and fine matching techniques, which made a significant contribution to the conservation of cultural relics [28].

Jia Rui from Xi’ an University of Architecture and Technology proposes a content-based adaptive digital image restoration scheme for the mural painting, using the "Horse Ball" excavated from the tomb of Prince Zhang Huai of the Tang Dynasty as an example. It divides mural restoration into two parts, namely the part with structure and texture information and the flatter ground part which is relatively blank and conveys less information. With sample block image restoration algorithm, the restoration of the whole painting is achieved. It can be better applied to artifacts with complex structures, rich texture information, and large restoration areas, while the FMM fast image restoration algorithm is chosen for the ground layer part, which greatly improves the restoration speed and achieves good results overall [29] .

Deng Chan from Ningxia University proposes a restoration algorithm based on improving the traditional TV model that is applied to the virtual restoration of the rock painting of Donkey Ditch. The traditional TV model image restoration algorithm only works well for small areas of broken images, and the fluctuation of parameters in the restoration process has a great impact on the restoration results. In order to alleviate this deficiency, a diffusion coefficient was added to the traditional TV restoration model by combining the nonlinear diffusion principle in the research process, which effectively controls the diffusion in the edge region, increases the diffusion range in the smooth region. It achieves better results for petroglyph restoration, but there are also defects such as poor visual coherence [30] .

Yang Suobei of Beijing University of Architecture proposes a regression model-based method for predicting the size of missing parts of cultural relics for restoration, which is applied in the restoration of the Thousand Hand Buddha of the Dazu Rock Carving in Chongqing. Firstly, the skeleton lines of the Thousand Hand Buddha are extracted and a 3D model is established. Secondly, the well-preserved finger skeleton lines are measured, and their lengths and diameters are counted and analyzed. Finally, a prediction model that can predict the length of the missing fingers of Thousand Hand Buddha is established. The length of the missing finger of Thousand Hand Buddha is restored by this model [31] .

3.1.3 Color repair of fading and discolored areas

In response to the serious degradation of the Houma League Book in Shanxi, Suzhen Lin of North Central University proposes a virtual restoration scheme using morphological operations for burr removal and uniform expansion of the skeleton. Firstly, the captured RGB color is transformed to obtain HSV spatial brightness images to highlight the target. Then the eight-neighbor threshold pixel value analysis method is used to extract text skeleton information and remove image noise to restore the stroke segments. Finally, the human-computer interaction mode is used to repair the stroke details and color migration correction of the inscription outline to make the image more consistent with the human visual characteristics [32] .

Yame Li from Chongqing University proposes a method of virtual restoration of ancient frescoes based on Photoshop implementation. She proposes the basic methods and operational procedures of fresco color restoration, and carries out an operation in specific frescoes, which could direct color restoration of faded and discolored areas of frescoes practically [33] .

3.2 Analysis of the current situation

3.2. 1 Preference for theoretical research

At present, virtual restoration research in China is more focused on theoretical research in universities, while in specific cultural heritage conservation, virtual restoration is not popularized and cannot play an ideal role due to the difficulty of technical operation, the need for professional personnel, insufficient conservation funds to support the establishment of a long-term virtual restoration system, and insufficient recognition of the value of virtual restoration.

3.2.2 Technical failure of virtual restoration of cultural heritage

Digital image restoration techniques, which mainly consist of image enhancement, image virtual restoration, color restoration, stitching of damaged relics, etc. [34]. Such algorithms are prone to restoration blurring and image misalignment for complex and large mural images, and there are

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limitations in restoration scope.

At the same time, virtual restoration is currently most applied to the collection of cultural heritage data information, which are also difficult to be transformed into actual restoration effects in the short term. Therefore, they cannot guide the subsequent conservation work of cultural heritage, and the scope of application is too small in the whole process of cultural heritage conservation [35] .

3.2.3 Lack of joint use of various virtual restoration techniques

At present, the application of virtual restoration technology is still relatively scattered in the field of cultural heritage conservation, and the advantages and disadvantages of each technology have not yet been clearly cognized. In addition, the lack of joint use of various virtual restoration technologies makes it difficult to achieve complementary advantages. The conservation problems are relatively complex for a cultural relic, for which various virtual restoration techniques are required in the preliminary survey, data measurement, disease research, the mid-term conservation program design, and later environmental monitoring and control. And the cognition of virtual restoration techniques should transcend the boundary of the virtual world to the real conservation work to guide the conservation of cultural heritage.

4. The direction of virtual restoration technology in cultural heritage conservation

4.1 Establishment of cultural heritage database

Cultural heritage database is the foundation of cultural heritage protection, thus the database should be designed comprehensively. 3D point cloud data model of cultural heritage is established through 3D laser scanning technology to accurately measure the size of cultural heritage; the surface information of cultural heritage is recorded in detail; and the diseases of cultural heritage are accurately identified [36] . In addition, a data sharing platform should be established to realize data cooperation among various cultural heritage protection units to ensure the circulation of technology and information.

4.2 Improving the hardware and software design of virtual repair

For virtual restoration of cultural relics, the restoration process constantly repeats and cyclically computes both in the establishment of digital models of cultural relics and the establishment of 3D models through laser scanning. This process causes a great burden to the computer hardware, as a result, the hardware system cannot drive the software system to work smoothly, and the phenomenon of lagging occurs in the restoration. It is also necessary to continuously improve the sense of reality of the 3D model scene, and the research on textures should be developed in the direction of meticulousness and high resolution [37] .

4.3 Establishment of principles and standards for virtual restoration

Virtual restoration is also a form of cultural heritage conservation, so it is important to establish principles and standards for virtual restoration to ensure that virtual restoration develops in a standardized direction. When establishing principles, on the one hand, the principles of physical cultural heritage conservation should be referred to. On the other hand, the requirements for cultural heritage conservation in virtual restoration practice should be combined to develop standards suitable for virtual restoration. Because it is not ontological conservation, there is no damage to cultural relics, which means the most basic principle in virtual restoration is to ensure the accuracy and comprehensiveness of information about cultural relics [38] . When establishing standards, the advantages and disadvantages of current virtual restoration effects and its contribution to cultural heritage conservation should be thoroughly summarized, and the standards should be as detailed and data-based as possible to avoid interference of subjective views in the process of virtual restoration, which may affect the value of cultural heritage manifestation and the physical conservation of cultural heritage [39].

4.4 Cultivate professional virtual restoration talents

Virtual restoration technology requires high professional operation techniques. Professional talents should not only completely understand various virtual restoration methods, software, equipment, but

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also have basic knowledge of heritage conservation and certain aesthetic appreciation. Hence, it is necessary to cultivate diverse talents, who should understand cultural heritage, history, art, information science and so on. It is also necessary to form a professional virtual restoration team. At the same time, joint talents training with various technology companies also counts a lot, which contributes to further implementation of Science + Cultural Heritage.

5. Conclusion

Through the analysis of virtual restoration technology, this paper finds that there are still numerous shortcomings in the application of virtual restoration technology in the current situation of cultural heritage conservation. For example, virtual restoration technology is still in the preliminary stage of theoretical research with great technical difficulties, and there are problems like the need for professional personnel, insufficient funds to support the long-term establishment of virtual restoration systems, inadequate value recognition, low technical level, the independent use of various technologies with few joint and so on Nevertheless, the application of digitalization in the field of cultural heritage conservation is becoming more and more popular, and the techniques are developing constantly. The interdisciplinary research is no longer simply limited to the study of a specific field, and it has become an inevitable trend in the future development of science and technology [40] .

Although there is still a long way to go before achieving the combination between the practical application of virtual restoration technology in cultural heritage conservation and the existing technology, the development of digital technology is dynamic and incessant, and techniques are constantly evolving and improving It is believed that virtual restoration technology will play an irreplaceable role in cultural heritage conservation, which can ensure the subjectivity and safety of culture and create cultural heritage conditions that meet the characteristics of the times. Moreover, it can put our cultural heritage conservation into practice, thus promoting cultural heritage with a new vitality and helping the preservation and protection of traditional culture and the dissemination of cultural heritage values.

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