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Computer-Aided Design AND APPLICATIONS

Digital Restoration and Innovative Design of Ancient Books Based on CAD and Big Data Technology

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Abstract. The purpose of this article is to discuss the digital restoration and innovative design method of ancient books based on computer-aided design (CAD) and big data technology. Aiming at the challenges faced by the digital restoration of ancient book images, this article proposes an innovative solution. This method combines the accurate modelling of CAD technology with the powerful analysis ability of big data technology. Through the experimental verification of RCdata and FCdata data sets, the efficient and accurate restoration of ancient book images is realized. In terms of methods, this article constructs an efficient feature extraction network and combines advanced up-sampling technology and CAD to capture and restore rich texture details in ancient book images. At the same time, a large number of ancient book image data are collected and sorted by using big data technology, which improves the learning ability of the algorithm for ancient book image features. The results show that the algorithm proposed in this article has obvious advantages in local texture detail reconstruction, error control, feature matching, and alignment, but it is time-consuming. Compared with traditional algorithms, this algorithm improves the accuracy and efficiency of the digital restoration of ancient book images and provides a new technical means for the inheritance and development of ancient book culture.

Keywords: Ancient Books; Digital Restoration; Cad Technology; Big Data; Feature Extraction
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1 INTRODUCTION

As an important part of the treasure house of human knowledge, the value of ancient books lies not only in academic research but also in their cultural identity and spiritual inheritance [1]. Traditional preservation methods of ancient books, such as paper preservation and microfilm, have extended the life of ancient books to a certain extent, but it is still difficult to completely resist natural erosion and man-made damage [2]. Natural disasters such as fire, flood, moth-eaten, mildew, improper browsing, and poor preservation of the environment may all lead to irreversible damage to ancient books [3]. In addition, the scarcity and uniqueness of ancient books also make it more difficult to protect them. Once damaged, it is often difficult to recover. By converting ancient books into digital form, not only can physical damage be effectively avoided, but also information can be quickly retrieved and widely disseminated [4]. Digital technology makes it possible to share ancient books and resources, and people can access these valuable cultural heritages through the network no matter where they are [5]. Digitalization facilitates the in-depth study of ancient books, such as the application of text analysis, image recognition and other technologies, which can help scholars to mine the knowledge treasure in ancient books more efficiently.

Big data analysis can automatically identify subtle changes in the shape, colour, texture, and other aspects of cultural relics, and provide timely warnings of potential risks such as erosion and crack propagation. By combining CAD models with real-time monitoring technology, continuous monitoring of the status of cultural heritage can be achieved. These data are accurately registered and fused through advanced algorithms to form a highly consistent and complete digital model of cultural heritage. With the advent of the information age, the restoration of ancient cultural relics has shifted from the traditional "manual" approach to a fully digital approach that combines artificial intelligence, modern instruments, and virtual reality. This approach has the potential to be efficient, accurate, flexible, and non-destructive. Chinese ancient relics contain rich cultural, artistic, and scientific values [6]. To construct a contour model of a fully collapsed and deformed painted paint box, comprehensive collection and information processing analysis of one-dimensional, two-dimensional, and three-dimensional data of the paint box were conducted. However, excavated cultural relics have suffered varying degrees of damage due to long-term natural or human factors, seriously affecting their research and appreciation value. Therefore, the restoration of cultural relics is of great significance. The effectiveness of traditional cultural relic restoration methods heavily relies on the work experience and attitude of restoration personnel, resulting in a huge workload and low restoration efficiency, which can easily cause secondary damage to cultural relics. By utilizing computer 3D modelling technology, machine vision technology, and image restoration technology based on generative adversarial networks, the digital restoration and display of Han Dynasty wooden painted paint boxes have been achieved [7].

Chinese traditional culture has a long history, unique charm, and a profound mass foundation. Opera, calligraphy, painting, and other forms are important carriers for expressing and inheriting excellent traditional Chinese culture. Most existing style transfer algorithms are based on the transfer of Western oil painting styles, and overly abstract textures are not suitable for the expression of Chinese cultural elements such as opera. Based on convolutional neural networks, traditional culture is integrated with digital technology to innovate the styles of traditional clothing. For the first time, style transfer was combined with traditional clothing images to better showcase its artistic effect [8]. A new loss function was added based on the original loss function. The comparative experimental results with Prisma showed that the processed images in this paper were smoother and solved the problem of excessive abstraction caused by twisted lines. The digitization of opera costume patterns and the generation of new styles are of great significance, but the existing digital technology forms are monotonous, and manual design is difficult and inefficient [9]. The transferable style features are single, and the jitter generated by the artistic output of the video frame by frame affects the output effect. And optimize the selection of convolutional network frameworks and corresponding feature layers. Some scholars have further improved the relevant network structure and loss function, proposing to obtain images with different degrees of stylization by adjusting the content loss function and style loss function. Changing the weight coefficients of different styles can make the final transfer style tend towards a specific style. Solved the problem of single-style transmission, achieved the artistic transfer of multiple styles, and designed a new loss function to obtain a new style feature to enrich the expression of traditional culture.

The purpose of this study is to explore the application potential of CAD and big data technology in the digital restoration and innovative design of ancient books, to achieve the following goals:

Using CAD technology, the high-precision digital restoration of the physical form of ancient books is realized, which provides a reliable basis for the in-depth study and protection of ancient books.

Combined with big data technology, the cultural elements and creative inspiration in ancient books are excavated, and the derivatives of ancient books with both traditional cultural heritage and modern aesthetics are designed.

Build a digital platform for ancient books, and use modern communication means such as virtual reality and social media to make the culture of ancient books closer to public life.

The introduction expounds on the present situation, the challenges of ancient book protection, and the emerging role of digital technology in ancient book protection. Then, the theoretical basis and methodology of the research are introduced in detail, including the specific application of CAD and big data technology. Then, the digital restoration process of ancient books based on CAD and the innovative design strategy of ancient books based on big data are discussed, and the actual effect of technology application is demonstrated through empirical research. Finally, the technical challenges and limitations are analyzed in the discussion part, and the research results are summarized in the conclusion, pointing out the research limitations and suggestions for future research.

2 THEORETICAL BASIS

CAD is the process of using computer technology for product design, analysis, and optimization. Tsilimantou et al. [10] use functions such as 2D drawing, 3D modelling, and rendering to help designers quickly and accurately implement their design concepts. Based on relevant historical materials and expert experience, the outline and structure of the wooden painted paint box were initially formed. Wang et al. [11] used the computer 3D modelling software 3Dmax to construct its primary model. Accurately calculate the three-dimensional spatial dimensions to refine the primary model of the paint box and obtain an accurate digital structural model of the painted paint box. Calibrate the three-dimensional collected data size based on the actual dimensions of the paint box unit and use the three-dimensional spatial curve distance formula to calculate the actual dimensions of the paint box. By comparing various image restoration algorithms, it was ultimately determined that the restoration method based on generative adversarial networks would be the core, and the image restoration effect would be improved by adding gated convolutional layers. The repair process includes pre-processing of paint box images, selection of areas to be repaired, and image restoration. Firstly, unit segmentation is performed based on the arrangement pattern of the lacquer box decoration, and preprocessing operations such as denoising, enhancement, and correction are performed on the segmented unit images to improve image quality. Wang et al. [12] studied that the key technology for digital restoration of lacquer box decorative patterns lies in reliable image restoration algorithms. Then, the preprocessed unit image to be repaired area is masked using an image mask. Finally, use image restoration algorithms to restore the unit images to be repaired. The experiment shows that the generative adversarial network repair algorithm with gated convolution can achieve more detailed repair effects. Through high-precision modelling and rendering using CAD technology, the original appearance of ancient books can be accurately restored; The introduction of big data technology can provide rich cultural elements and user behavior data support for innovative design of ancient books.

Ye [13] is committed to recording and protecting information on China's architectural heritage, but they are particularly concerned with establishing a new model of harmonious coexistence between architectural heritage and urban renewal in the process of sustainable urbanization in China. Specifically, advanced Building Information Modeling (BIM) technology is utilized to accurately digitize and model the site by integrating two-dimensional (2D) drawings, component information, and high-precision three-dimensional (3D) scanning data. This process not only captures the geometric shape of the building but also combines complex information such as materials and structures, providing a detailed data foundation for subsequent maintenance, monitoring, and protection. Taking the former site of the Temporary Senate of the Nationalist Government in Nanjing as an example, this paper explores the cutting-edge application of computer-aided design in the digital protection of cultural heritage in the big data environment. At the same time, by creating a component "family" library, we have systematically classified and standardized the management of common historical building components, enabling future digital protection work to more efficiently and accurately reuse existing achievements and accelerate the digitalization process. The core of this goal is to use scientific and standardized classification methods to integrate architectural heritage information into a multi-level and multi-dimensional digital framework, to achieve more accurate and efficient protection and management. The combination of big data and CAD technology has also promoted the intelligent development of digital protection of cultural heritage. In addition, Zhong et al. [14] utilized big data analysis techniques to conduct in-depth mining of massive architectural heritage data, identifying typical features, evolutionary patterns, and potential risk points of historical buildings. This step is of great significance for developing targeted protection strategies and optimizing resource allocation. In addition, BIM-based virtual reality (VR) and augmented reality (AR) technologies provide the public with an immersive cultural heritage experience platform, enhancing the dissemination and influence of cultural heritage. For example, by using intelligent monitoring systems to collect real-time status data of architectural heritage, utilizing big data analysis to predict potential threats, issuing warnings and taking corresponding measures, the full lifecycle management of architectural heritage can be achieved. The rise of big data has provided unprecedented opportunities for museums to gain a deeper understanding of audience needs, collection value, and market trends. In this context, Zhao et al. [15] believe that "digital authorization" has become one of the key strategies for museums to achieve financial self-sufficiency and sustainable development. The immutability, decentralization, and automatic execution of smart contracts in blockchain provide a transparent and trustworthy environment for the authorization, distribution, trading, and profit distribution of digital collectables. These digital achievements not only enrich the exhibition forms of museums but also broaden the dissemination channels of cultural heritage, attracting more young audiences and remote participants' interest.

3 DIGITAL RESTORATION OF ANCIENT BOOKS BASED ON CAD AND BIG DATA

As a powerful tool for 3D modelling and design, CAD is used for the digital restoration of ancient books in this study. The physical shape information of ancient books is obtained by high-precision scanning and photography technology, and then 3D modelling is carried out in CAD software to accurately restore the paper texture, handwriting shape, binding structure and other details of ancient books. In addition, the rendering function of CAD can also simulate the display effect of ancient books under different lighting conditions, providing a realistic visual experience for digital publishing and virtual exhibition of ancient books. In the aspect of data analysis, this study adopts the method of combining quantitative analysis with qualitative analysis. Quantitative analysis: By counting the text and image data in the database of ancient books, the quantitative indexes such as keyword frequency, topic distribution, and color ratio are calculated, and the information structure and visual characteristics in ancient books are revealed. Qualitative analysis: based on quantitative analysis, combined with historical background, cultural traditions, and other factors, the ancient books are deeply interpreted and explained.

In the journey of digital restoration of ancient books, technological innovation is the key force to promote this process. This section will deeply discuss how to integrate CAD and big data technology and realize high-precision digital restoration of ancient book images by constructing an innovative pyramid generation network structure. Figure 1 shows an innovative pyramid-generating network structure, which consists of two core branches: the super-resolution (SR) branch and the Gradient Branch.

SR branch: As the core part of the network, the SR branch is responsible for extracting feature information from low-resolution (LR) images and generating SR images. This branch gradually learns and optimizes the feature representation of LR images through a multi-layer structure. The S1 layer and S2 layer contain 18 and 6 residuals in residual dense blocks (RRDB), respectively. These RRDB blocks effectively capture the high-level features of images through dense connection and residual learning mechanisms.

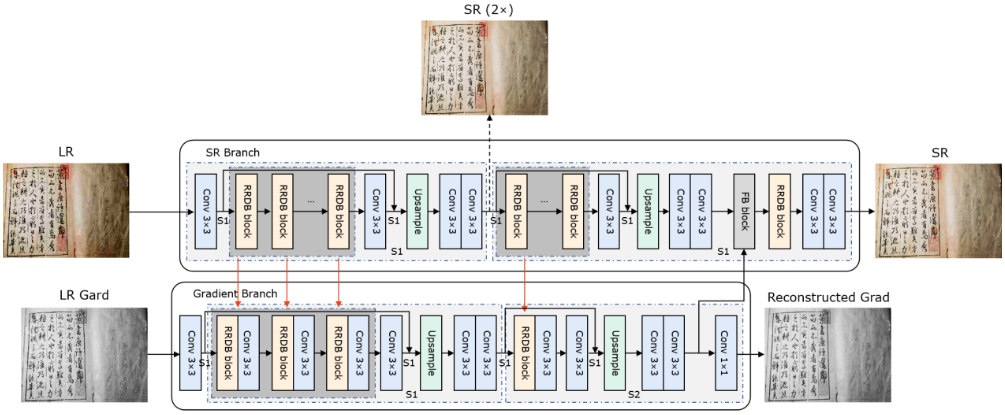

Figure 1: Pyramid generation network structure.

In the first 23 RRDB blocks, the network focused on extracting the feature information of LR images, while the last RRDB block cooperated with the convolution layer for the final SR feature information reconstruction.

Define the grey function of the ancient books' two-dimensional image $f(x,y)$. The r $(r>0)$ domain for the pixel at position (i,j) is specified by the set:

$$N_r(i,j) = \{(k,l) \mid \max(|i-k|,|j-l|) \le r\} \tag{1}$$

The degree of interest for (i,j) bit pixels is defined as follows:

$$I(i,j) = \frac{1}{(2r+1)^2-1} \sum_{(k,l)\in N_r(i,j)} \left[f(i,j) + w(k,l,\sigma) f(k,l) \right] \tag{2}$$

Where:

$$w(k,l,\sigma) = \psi(i-k, j-l, \sigma) \tag{3}$$

$\psi(x,y,\sigma)$ represents a DOG function.

Gradient branch: In parallel with the SR branch, the gradient branch focuses on processing gradient information of images to provide structural prior knowledge to assist the restoration process. The gradient branch consists of the S1 layer and S2 layer, including 3 and 1 basic blocks, respectively. Each basic block consists of an RRDB block and a convolution layer with a convolution kernel of 3×3. This branch first converts the gradient map of the LR image into a reconstructed gradient map, which aims to capture the edge and texture details in the image and provide accurate structural guidance for the generation of the SR image.

In the pyramid generation network, the feature fusion block is responsible for effectively fusing the feature information of the SR branch and the gradient branch, thus ensuring that the generated SR image not only contains rich detailed features but also maintains structural accuracy. This fusion process is realized by a well-designed algorithm, which ensures the optimal integration of feature information.

In this study, the sub-pixel convolution technique is used for up-sampling. This method realizes the effective conversion from low resolution to high resolution by rearranging pixels while maintaining the details and clarity of the image. Compared with the traditional interpolation method, sub-pixel convolution can recover the high-frequency information of the image more accurately, thus generating a more realistic and delicate SR image.

The feature map in CNN is calculated using the formula:

$$m_i = f\ \ D^{*}F_i + b_i \tag{4}$$

Here, $*$ denotes convolution calculation, b_i signifies an offset term and $f\ \cdot$ represents the activation function. Suppose the feature map derived from the t convolution layer is:

$$M_t = \ \ m_1, m_2, m_3, \ldots, m_s \tag{5}$$

Maximum pooling extracts the highest value from M_t . p_i signifies the pooling outcome of the t_i convolution layer, expressed as:

$$p_i = \max\ M_t\ = \max\ m_1, m_2, m_3, \ldots, m_s \tag{6}$$

Figure 2 shows the structure of the RRDB block, which is the basic unit of the pyramid generation network. RRDB block realizes the efficient extraction and representation of image features through the combination of residual learning and dense connection. In the RRDB block, multiple convolution layers and activation function layers are skillfully organized to form a deep feature extraction network. This structure enhances the learning ability of the network and improves the robustness of feature representation.

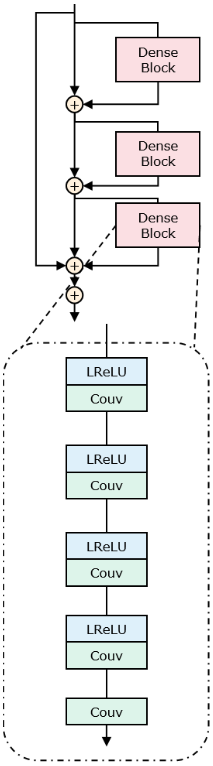

Figure 2: RRDB block structure.

In the SR branch, the role of the RRDB block is particularly prominent. By extracting feature information at different levels and effectively fusing this feature information, the RRDB block ensures that the network can capture subtle differences and unique features in ancient book images. Especially in the 5th, 10th, and 15th RRDB blocks of the S1 layer and the 5th RRDB block of the S2 layer, feature maps are merged into gradient branches, which further enhances the accuracy and effectiveness of gradient information. This design enables the network to restore the details and colours of the ancient books' images more accurately.

Applying ancient book version classification technology significantly cuts down matching instances. By substituting joint normalization with independent batch normalization for each dimension's data, we get the formula:

$$\widehat{X}^{k}=\frac{x_i^{k}-E\left[x^{k}\right]}{\sqrt{\operatorname{var}\left[x^{k}\right]}} \tag{7}$$

Here, x^{k} represents the k dimension of the input sample, $E\left[x^{k}\right]$ denotes the expectation, and $\operatorname{var}\left[x^{k}\right]$ signifies the variance. Incorporate parameters λ^{k} and β^{k} into the k dimension of each input sample, resulting in the formula:

$$y^{k}=\lambda^{k}\widehat{X}^{k}+\beta^{k} \tag{8}$$

With λ^{k} and $\operatorname{var}\left[x^{k}\right]$ being equal variances, we can obtain regional pixel information as follows:

$$L=J\ w,e\ -\sum_{i=1}^{N}a_i\ \ w^{T}\varnothing\ x_i\ +b+e_i+y_i \tag{9}$$

Here, $J\ w,e$ signifies repeated pixel points of ancient book image features, while x_i and y_i are the feature vectors of ancient book images for the i Gaussian unit. a_i Represents the standard action configuration sequence, and $\varnothing\ x_i$ denotes the contour feature distribution function. We estimate the probability of reduced-dimensional ancient book image features in the Gaussian unit:

$$r\ i\ =\frac{w_i p_i-v_i}{\sum_{i=1}^{k}w_i p_i\ \ v_i} \tag{10}$$

p_i denotes the probability assigned to the i-th Gaussian unit, with w_i as the mixing weight.

By collecting and sorting out a large number of ancient books' image data, big data technology provides rich resources for network training and optimization. These data are not only used for the initial training of the network but also for the subsequent fine-tuning and optimization process, which ensures that the network can constantly adapt to the new ancient book image characteristics.

4 EXPERIMENTAL RESULTS AND ANALYSIS

In the research of digital restoration of ancient book images, the selection of data sets and the design of algorithms are two core elements. In this study, the representative RCdata and FCdata datasets are selected as the experimental objects. Both datasets contain a large number of high-quality ancient book images, covering ancient book samples from different historical periods and regions, which provide rich resources for the training and testing of the algorithm.

4.1 Local Texture Detail Contrast

As shown in Figure 3, a reconstructed image is selected from RCdata and FCdata data sets, respectively, and some texture details in the image are enlarged. Among them, HR represents an enlarged picture of the texture details of the original high-resolution cultural relic image. By comparison, it can be seen that compared with other algorithms, the algorithm proposed in this article can capture and restore the texture details of the image more accurately when reconstructing the ancient book image. Whether it is the smoothness of lines, the depth of ink, or the texture of paper, the image reconstructed by this algorithm is closer to the HR cultural relic image, showing a clearer and more realistic visual effect.

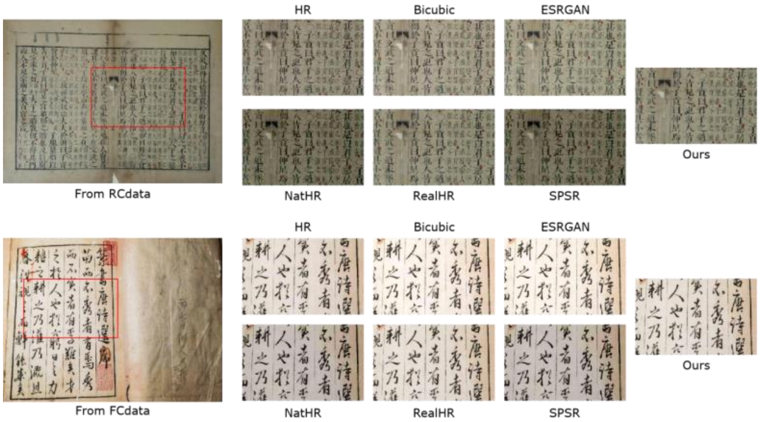

Figure 3: Comparison of local texture details.

This advantage is achieved thanks to the careful design of the algorithm in the process of feature extraction and reconstruction. By constructing a pyramid-shaped generating network and combining it with advanced technologies such as RRDB block and feature fusion block, the algorithm can efficiently extract rich feature information from low-resolution images, and maintain the accuracy and integrity of these features during the up-sampling process.

4.2 Error Analysis

To further assess the performance of the algorithm, an error comparison is made between the training set and the test set. As shown in Figure 4 and Figure 5, compared with the traditional algorithm, the algorithm in this article shows different advantages in error control. On the training set, the error curve of this algorithm is more stable, and the convergence speed is faster. On the test set, the error of this algorithm is also significantly lower than other algorithms, showing stronger generalization ability.

This result is obtained thanks to the optimization strategy of the algorithm in the training process. By introducing big data technology, a large number of ancient books image data can be collected and arranged for network training and optimization. These data enrich the sample diversity of the training set and improve the learning ability of the algorithm for ancient book image features.

4.3 Feature Matching and Alignment Results

Feature matching and alignment are the key steps in the mosaic and restoration of ancient book images. As shown in Figure 6, the surface features extracted from the original model often contain a lot of noise and redundant information, which brings difficulties to subsequent stitching and repair. However, using the completely matched feature matching and pairwise alignment results (as shown in Figure 7) can reduce the error to a certain extent, but it is difficult to ensure the correctness of the results, especially when only a small part of the model to be assembled fits.

Therefore, this study proposes a feature matching and pairwise alignment method of partial matching (as shown in Figure 8). By considering the continuity of the surface texture of the model to be spliced, the matching relationship of feature points can be judged more accurately, and accurate alignment can be realized.

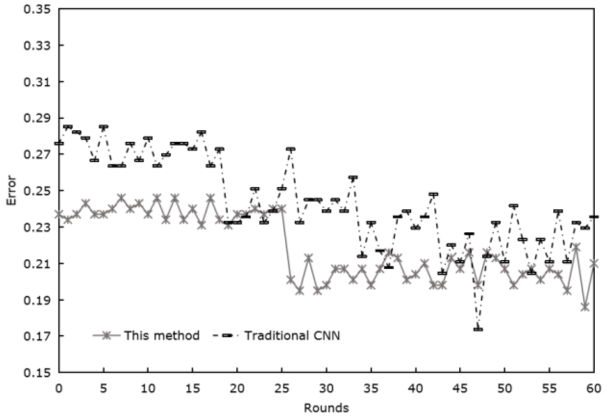

Figure 4: Error of different algorithms on the training set.

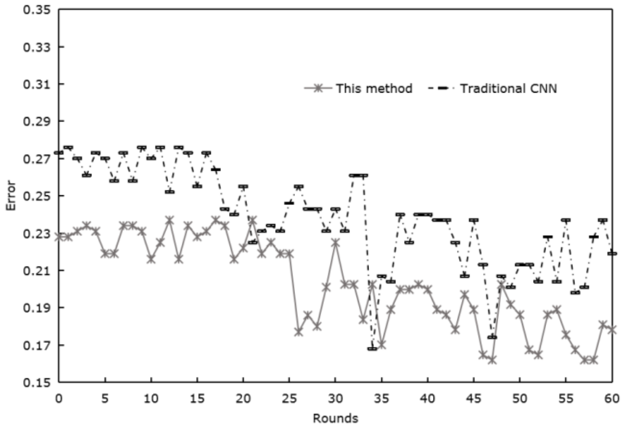

Figure 5: Error of different algorithms on the test set.

Figure 6: Original model and its surface features.

4.4 Time-Consuming Comparative Analysis

As shown in Figure 9, the time-consuming situation of different methods in ancient books' image information restoration is compared. It can be seen that with the increase of the number of feature information pixels, the time-consuming of the traditional CNN method shows a significant upward trend. Although the time consumption based on this algorithm has also increased, it has obvious advantages compared with the traditional CNN method.

Figure 7: Complete matching and alignment results.

Figure 8: Partial matching and alignment results.

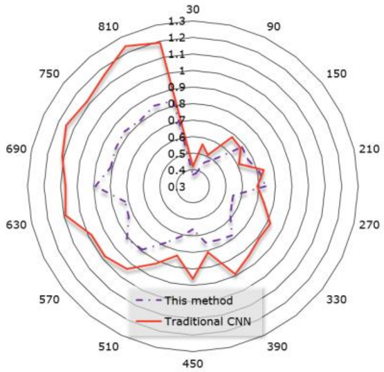

Figure 9: Time-consuming repair of ancient books by different methods.

By introducing advanced technologies such as RRDB block and feature fusion block, the algorithm can extract and process feature information more quickly, thus shortening the repair processing time. At the same time, by optimizing the key steps such as up-sampling and feature matching, the algorithm further improves the processing efficiency, making the restoration of ancient book image information more efficient and fast.

4.5 Discussion

In the research of digital restoration of ancient book images, the algorithm proposed in this article has shown remarkable advantages in many aspects. First of all, in the reconstruction of local texture details, this algorithm performs well. Ancient book images often contain rich texture information, such as the smoothness of lines, the depth of ink and the texture of paper. Through comparative experiments, it is found that the algorithm in this article can capture and restore these texture details more accurately when reconstructing the ancient books image, which makes the reconstructed image closer to the original high-resolution cultural relics image. This advantage is mainly due to the fine design of the algorithm in the process of feature extraction and reconstruction and the introduction of big data technology. By constructing an efficient feature extraction network and combining it with advanced up-sampling technology, the algorithm can efficiently extract rich feature information from low-resolution images.

In error control, this algorithm also shows obvious advantages. The error of this algorithm is lower than other traditional algorithms, both in the training set and test set. The achievement of this result is mainly due to the optimization strategy of the algorithm in the training process. By introducing big data technology, a large number of ancient books image data can be collected and arranged for network training and optimization. These data enrich the sample diversity of the training set and improve the learning ability of the algorithm for ancient book image features. In the aspect of feature matching and alignment, a partial matching feature matching and pairwise alignment method is proposed. This method solves the problem that the traditional complete matching method is difficult to ensure the correctness of the results. By considering the continuity of the surface texture of the model to be spliced, the matching relationship of feature points can be judged more accurately and accurate alignment can be realized. In terms of time consumption, this algorithm also shows obvious advantages. With the increase of the number of pixels of feature information, the time consumption of the traditional CNN method shows a significant upward trend; Although the time consumption based on this algorithm has also increased, it has obvious advantages compared with the traditional CNN method. This advantage is mainly due to the efficient design of the algorithm in the process of feature extraction and reconstruction.

These advantages not only benefit from the fine design of the algorithm in feature extraction, reconstruction and error control but also benefit from the introduction and application of big data technology. In the future, we will continue to deeply study the digital restoration technology of ancient book images, constantly optimize the algorithm design, and make greater contributions to promoting cultural inheritance and innovation.

The application of the algorithm in the digital restoration and innovative design of ancient books also faces many challenges, such as the complexity of ancient books' images, the accuracy requirements of 3D modelling and the calculation amount of big data analysis. However, it is these challenges that inspire the enthusiasm of researchers for continuous exploration and innovation. Looking forward to the future, with the continuous progress of algorithm technology, we are confident to overcome these problems and open up a broader road for the protection and dissemination of ancient books. Through the close combination of algorithms and artificial intelligence technology, the protection and dissemination of ancient books will be promoted to the direction of intelligence and individuation, and the ancient books culture will glow more brilliantly in the new era.

5 CONCLUSIONS

This article discusses the present situation and challenges of the digital restoration of ancient book images and puts forward an innovative solution combining CAD technology and big data technology. The experimental results on RCdata and FCdata datasets fully demonstrate the remarkable advantages of the proposed algorithm in local texture detail reconstruction, error control, feature matching and alignment, and time-consuming.

In this study, by constructing an efficient feature extraction network, combined with advanced up-sampling technology and CAD, the rich texture details in ancient book images are accurately captured and restored. The introduction of big data technology not only enriches the sample diversity of the training set but also improves the learning ability of the algorithm for ancient book image features, thus showing obvious advantages in error control. In addition, the feature matching of partial matching and the method of pairwise alignment solve the problem that the traditional complete matching method makes it difficult to ensure the correctness of the results and improve the accuracy of ancient books' image mosaic and restoration.

The proposed algorithm not only improves the accuracy and efficiency of the digital restoration of ancient book images but also provides a new technical means for the inheritance and development of ancient book culture. In the future, we will continue to study the digital restoration technology of ancient book images, constantly optimize the algorithm design, explore more technological innovations, and contribute more to the protection and inheritance of ancient book culture.

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