The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-9-2025
30th CIPA Symposium "Heritage Conservation from Bits:
From Digital Documentation to Data-driven Heritage Conservation", 25–29 August 2025, Seoul, Republic of Korea

Digital Conservation of Ancient Woodblock Combining Hyperspectral Imaging and Close-range Photogrammetry Technology

Shun Ma[1,2], Shuqiang Lyu[1,2], Wangting Wu[3], Miaole Hou[1,2,*], Wenyi Cui[1,2]

[1] School of Geomatics and Urban Spatial Informatics, Beijing University of Civil Engineering and Architecture, No.15 Yongyuan Road, Daxing District, Beijing, China -201904010210@stu.bucea.edu.cn, lvshuqiang@bucea.edu.cn, houmiaole@bucea.edu.cn, 2108570424016@stu.bucea.edu.cn.
[2] Beijing Key Laboratory for Architectural Heritage Fine Reconstruction & Health Monitoring, No.15 Yongyuan Road, Daxing District, Beijing, China.
[3] Capital Museum, No.16 Fuxingmen Outer Street, Xicheng District, Beijing, China-wangtingwu@126.com.

Keywords: Hyperspectral Imaging, Image enhancement, Close-range Photogrammetry, Structural information, Patch-based Inpainting

Abstract

The ancient woodblocks were typically used as engraving plates for printing books and served as important tools for the dissemination of culture, scholarship, and religion. However, due to the long survival time and the influence of the natural environment, the woodblocks have suffered different degrees of damage, with blurred inscriptions or lost information. Therefore, we propose a digital protection method based on hyperspectral image and close-range photogrammetry technology. Firstly, by virtue of the high spectral resolution and penetrability of hyperspectral imaging, we synthesized the image of the woodblocks with different bands selected from the hyperspectral image, which was enhanced by combining the low-light illumination map estimation (LIME) and the dark-channel algorithms. It can improve the detailed information in the woodblocks. Secondly, due to the existence of multiple damage in the woodblocks, we proposed a digital restoration method that enhance the structural information to restore cracks and missing regions in the woodblocks. During the restoration process, a curvature function was introduced into the data term to address the issue of insufficient consideration of structural information in traditional patch-based algorithms. A boundary function is incorporated to prioritize the restoration of regions with distinct structural features. The method was validated on the Tripitaka woodblocks produced during the Emperor Qian Long period of Qing Dynasty, China (A.D. 1736-1796). The experimental results show that the method can effectively restore the damage and reveal more detail information on the woodblocks. It can provide a feasible technical solution for the digital conservation of the ancient woodblocks.

1. Introduction

Ancient woodblocks are precious cultural relics in the treasure house of culture. They are not only an important part of the splendid Chinese culture but also possess extremely significant historical and cultural value. Moreover, they are exquisite works of art with exquisite carvings (Kang et al., 2009). However, due to environmental and time factors, the woodblocks are suffering from various damages such as content loss, blurred characters, and surface scratches. Therefore, the protection of the woodblocks is particularly important. With the development of modern technology, the protection of cultural relics tends to use digital technology. It not only does no harm to the relics themselves but also provides a permanent and replicable database for these cultural heritages. This article introduces how to use modern digital technology to digitally protect the woodblocks and preserve their value.

With the advancement of technology, an increasing number of non-destructive testing techniques have been widely applied in the field of cultural heritage protection. As an advanced non-contact detection method, hyperspectral imaging technology can deeply excavate and detect information including pigment components and surface characteristics, which is widely used in the analysis and conservation of artworks and cultural relics (Zhang et al., 2023). The advantages of using hyperspectral imaging data to excavate hidden information on mural surfaces, combined with enhancement methods for information mining of the murals in Qutan Temple (Gao et al., 2023). By performing Minimum Noise Fraction (MNF) processing on hyperspectral images, mean gradient and cross-entropy were introduced to extract the strips of hidden paintings (Chen et al., 2022). Accurately identifying diseases in paper cultural relics through hyperspectral imaging (Dai et al., 2022). Close-range photogrammetry technology can effectively obtain accurate shape and size information of cultural relics. By means of image restoration algorithms, it can carry out virtual restoration of cultural relics and restore their aesthetic appearance (Alsadik et al., 2019). Yao F proposed improvements to the Criminisi priority calculation, adaptive adjustment of template window size, and optimization of matching criteria in Thangka mural images to enhance the restoration effect (Yao et al., 2019).Wang proposed a sample block sparse model method guided by line drawings for Dunhuang mural restoration (Wang et al., 2019). Similar to murals, woodblocks also face the problem of diseases. We introduced hyperspectral technology to the detection of woodblocks and combined it with image restoration technology to excavate hidden information, restore the original appearance of woodblocks, and thereby provide a scientific basis for the digital preservation and restoration of woodblocks.

The main contributions of this paper include the following three points: (1) Conducting hyperspectral and close-range photogrammetric photography of woodblocks to acquire hyperspectral imagery and orthophoto data, providing basic data for woodblock research. (2) Synthesizing true-color imagery from hyperspectral data and using image enhancement techniques to excavate information from woodblocks, providing a basis for studying the cultural value of woodblocks. (3) Using digital restoration techniques to repair woodblock orthophotos, filling in defects, restoring the appearance, enabling virtual restoration of woodblocks, and ensuring non-contact digital preservation.

2. Data and Methods

2.1 Samples and Data Acquisition

The *Qianlong Tripitaka* is an official Chinese Buddhist canon printed in the Qing Dynasty. It began in the 11th year of the Yongzheng reign (A.D.1733) and was completed in the 3rd year of the Qianlong reign (A.D.1738). With its meticulous proofreading and exquisite craftsmanship, it represents the highest standard of block printing in the Qing Dynasty. Meanwhile, as a Buddhist printed work, the *Qianlong Tripitaka* is a peak work of printmaking art, featuring delicate lines, exquisite painting and carving, and a solemn atmosphere (Zhao et al., 2023). As shown in Figure 1, the woodblocks of the Qianlong Tripitaka have suffered diseases such as content loss, blurred handwriting, and scratches due to time and environmental factors. To protect the woodblocks and unleash their historical and cultural value, this paper uses digital technology methods to carry out digital preservation of the woodblocks of the *Qianlong Tripitaka*.

Figure 1. Version of the Qianlong woodblocks

We use the VNIR/400H hyperspectral imager from Themis Vision System to acquire hyperspectral data of 123 scenes of the Qianlong Tripitaka woodblocks in the collection. The acquired hyperspectral images have total pixels of 1392×1000, a sampling interval of 0.6 nm, and a spectral resolution of 2.8 nm, covering the spectral range of 400-1000 nm, including visible and near-infrared bands, with a total of 1040 bands. As shown in Figure 2, the hyperspectral instrument is used to photograph the woodblocks.

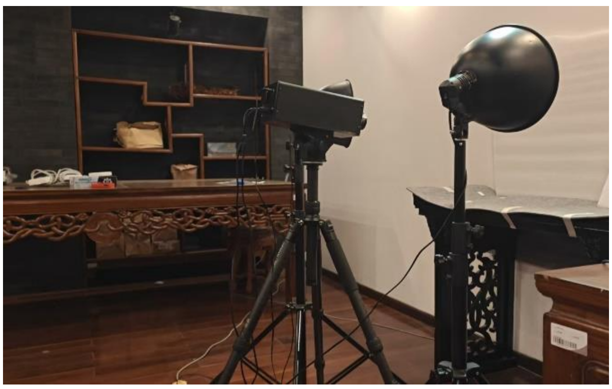


Figure 2. Hyperspectral photography

2.2 Proposed Method

Figure 3 shows a series of digital preservation processes for the Tripitaka woodblocks: (1) Data acquisition of woodblocks: Since hyperspectral data results are affected by different environmental lighting and dark current noise, first, the spectral reflectance was normalized with a white standard reflectance measured on a Spectralon plate, and the final data undergoes MNF denoising processing.(2) Hidden information extraction: True-color imagery synthesized from hyperspectral images is used for image enhancement. Algorithms such as LIME (low-light illumination map estimation) and dark-channel are employed to enhance the fonts on the sides of woodblocks, restoring the color of the characters.(3) Restoration of defects and cracks in woodblocks: By improving the sample block algorithm, introducing a curvature function into the data term to enhance structural information consideration, and adding structural elements to the priority, the original appearance of the woodblocks is restored.

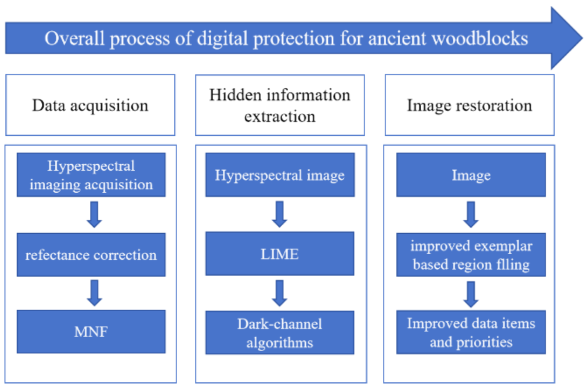


Figure 3. Overall flow chart

2.2.1 Data Preprocessing

During the data acquisition process, the data will be affected by environmental factors and the dark current of the instrument. Reflectance correction can be performed., and the correction formula is:

$$R = \frac{R_{Data} - R_{Dark}}{R_{White} - R_{Dark}} \times 99\% \qquad (1)$$

Where R is the reflectance; R_{Data} is the hyperspectral data; R_{Dark} is the dark current data; R_{White} is the reflectance of 99% standard reflector data.

MNF is a common dimensionality reduction and denoising operation in hyperspectral data processing. It is essentially two cascaded principal component transformations (Gao et al., 2024). MNF concentrates hyperspectral images onto several main bands and selects the first few bands for MNF inverse transformation can reduce data noise.

2.2.2 Image Enhancement

With the influence of various factors, the font colors on the woodblocks have become dim and covered by harmful substances, obscuring the original colors and details of the woodblocks, damaging their aesthetic appearance, and affecting their research value. In order to protect the original colors and details of the woodblocks, we synthesize true-color images from hyperspectral imagery and use LIME and dark-channel algorithms to enhance the red characters on the sides of the woodblocks, making the dim red characters more vibrant. LIME improves the visibility of low-light images by estimating the illumination map for each pixel, and the formula is expressed as follows:

$$L(x) = I(x) \cdot T(x) \quad (2)$$

Where $L(x)$ is the original image of the woodblock, i.e., the true-color image, $I(x)$ is the image to be restored, $T(x)$ represents the illumination intensity in the image. ϵ is an extremely small positive constant, and its main function is to prevent the denominator from being zero. Finally, image restoration is performed through Equation (3), expressed as:

$$I(x) = \frac{L(x)}{T(x)+\epsilon} \quad (3)$$

To improve the accuracy and smoothness of the dark channel map, a minimum filter can be applied to surrounding pixels to find the minimum grayscale value in the neighborhood and assign this value to the current pixel, thereby obtaining a more precise dark channel map. The expression of the dark channel prior is as follows:

$$R^{dark}(x) = \min_{y\epsilon\Omega(x)}(\min_{c\epsilon\{r,g,b\}} R^C(y)) \quad (4)$$

For each pixel x, in its surrounding neighborhood region $\Omega(x)$, for each pixel y, the minimum value is taken from the RGB channel. Then, the minimum value is taken again from these minimum values to obtain the dark channel value $R^{dark}(x)$. As shown in Figure 4, it is Xiang 8-10-04, the text part on the side of the forme. This is the red-character image on the side after algorithmic enhancement. Figure 4(a) is the true-color image, and Figure 4(b) is the enhanced image. It can be clearly observed that the fonts on the woodblock become more vivid and distinct, indicating that this should be the catalog guide in the Tripitaka.

(a) (b)

Figure 4. Enhancement Effects of Xiang 8-10-04(a) True-color Image; (b) Enhanced Image

2.2.3 Image Restoration Algorithm

Due to the woodblocks being afflicted by various damages such as delamination, cracks, defects, and blurred handwriting, these damages are compromising the artistic and historical value of the woodblocks. To protect the woodblocks, digital image inpainting methods were used to repair the damages on the woodblocks. The traditional patch-based inpainting algorithm mainly consists of four steps. The first step is to calculate the priority function of the unknown region to determine the sample patches to be filled first. The priority function is composed of confidence and data terms, as shown in the following equation:

$$P(p) = C(p) \times D(p) \quad (5)$$

In the equation, $P(p)$ is the filling priority value of the pixel point p in the unknown region, $C(p)$ is the confidence term, and $D(p)$ is the data term.

The second step uses a similarity calculation formula to find the best matching patch in the known region. After calculating the target patch Ψ_p with the highest priority, the SSD (Sum of Squared Differences) matching criterion is employed to search for the most similar matching patch Ψ_q to Ψ_p in the source region Φ based on the information of valid points in the patch to be inpainted Ψ_p. This process is used to fill in the missing information of Ψ_p, expressed by the formula:

$$\Psi_q = \arg min\, d(\Psi_p, \Psi_q) \quad (6)$$

In the formula, $d(\Psi_p, \Psi_q)$ is the sum of squared color differences between the corresponding known pixels in the target patch Ψ_p and the sample patch Ψ_q. The third step is to update the confidence term, and the fourth step repeats the above steps 1-3 until the entire unknown region is inpainted.

Since the traditional patch-based algorithm does not comprehensively consider structural information, we use an improved patch-based algorithm for virtual restoration of the woodblocks. As shown in Figure 5, it is the flow chart of the entire restoration process. We take the orthophoto of the woodblocks generated by 3D laser scanning as the object, manually creates a mask image of the damage information, where the white part represents the damage on the woodblocks. The overall algorithm process is the same as the traditional algorithm, but improvements were made in the data term and priority function. To better maintain the integrity of image structures, this paper introduces the curvature function into the data term, and the improved data term formula is:

$$D(p)=\frac{|\nabla I_p^{\perp}\cdot n_p|}{\alpha}g(|k|) \tag{7}$$

In the formula,g (|k|) is an increasing function of the curvature k, with $g(|k|)=k^{n}$, where $k>0$ and $n \geq 1$.

To reduce the influence of high-gradient regions in the original image on the curvature calculation results, linear convolution shown in Equation (8) is used for smooth calculation of curvature, thereby effectively maintaining the structural coherence and integrity of the image when facing complex textures and edge variations. In this way, the curvature information can more accurately reflect the local features of the image, avoiding restoration distortion caused by excessive gradient changes.

$$k \approx \begin{pmatrix} \frac{-1}{16} & \frac{5}{16} & \frac{-1}{16} \\ \frac{5}{16} & -1 & \frac{5}{16} \\ \frac{-1}{16} & \frac{5}{16} & \frac{-1}{16} \end{pmatrix} \cdot \psi_p \tag{8}$$

In the improvement of priority, we introduce a boundary function to strengthen structural information, giving priority to the restoration of structural information. The boundary function parameter γ is set to 0.6, and α and β are set to 0.2 respectively, to ensure that the restoration order starts from the most important parts of the image structure. This thereby improves the confidence $C(p)$ of the subsequent repair patch p and increases the reliability of the restored information. The expression of the improved priority function is as follows:

$$P(p) = \alpha C(p) + \beta D(p) + \gamma B(p) \quad (\alpha + \beta + \gamma = 1)$$

$$\left(\bar{x} = \frac{\sum|x|}{N}, \ \bar{y} = \frac{\sum|y|}{N}\right) \tag{9}$$

$$B(p) = \frac{D_p}{D_q}$$

In the formula, $(\bar{x}, \bar{y})$ are the coordinates of the centroid O of the pixel points in the region Ω, D_p is the distance from O to p, D_q is the distance from O through point p to the boundary δΩ, and N is the number of pixel points in the region to be inpainted Ω.

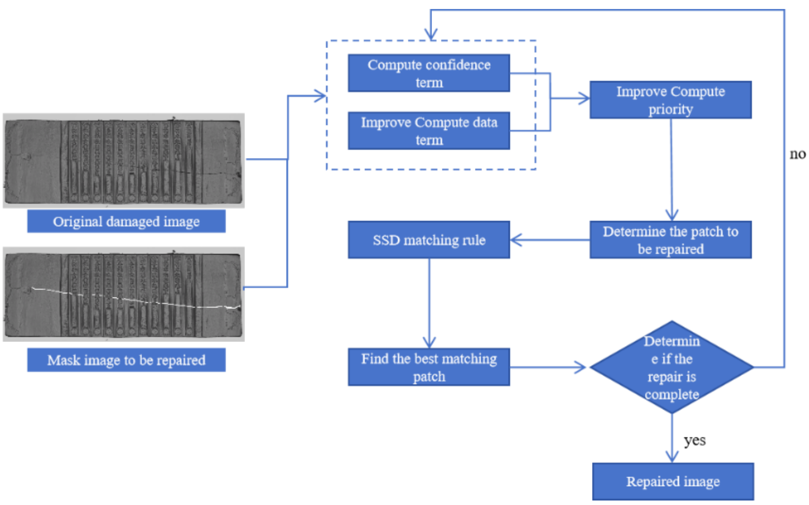
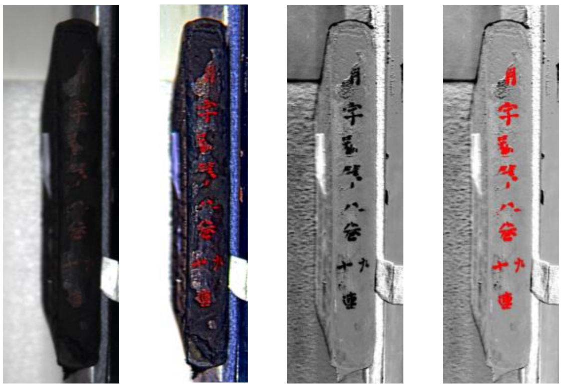


Figure 5. Algorithm Flow

3. Results and Discussion

3.1 Information Extraction

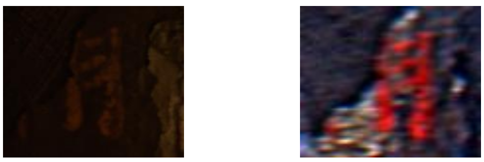
To observe the handwriting information on the woodblocks more clearly, leveraging the hidden information mining capability of hyperspectral data, MNF processing was performed on two woodblocks, Xiang 8-10-03 and Xiang 8-10-04. This aims to excavate woodblock information by utilizing spectral band data. Through forward MNF transformation, most useful information in the imagery is concentrated in the first few bands, allowing original data to be focused on specific bands for clear information display. As shown in the figures 6 for Xiang 8-10-03, image enhancement, MNF transformation, and information extraction were conducted. Figure 6(b) demonstrates that true-color composite images enhanced by LIME and dark-channel algorithms restore color information, verifying the algorithm effectiveness. Figure 6(c) shows MNF transformation results, where handwriting information on the woodblocks is extracted. Using MNF processing outcomes, handwriting in the image is extracted as shown in Figure 6(d), with red characters enabling intuitive visualization of text content. These operations restore color to dim handwriting on woodblocks and facilitate information mining.



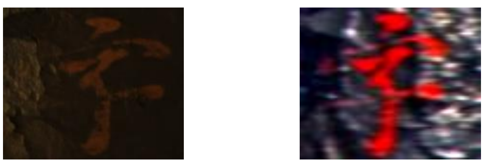
(a) (b) (c) (d)

Figure 6. Xiang 8-10-03 Information Extraction (a) Synthesis of True Color; (b) Image Enhancement; (c) MNF Processing; (d) Information Extraction Map

To verify the effectiveness of the image enhancement algorithm proposed, we compared the images captured by normal digital camera of woodblocks with their enhanced images, extracting the same handwriting for effect validation as shown in Figure 7. Handwriting samples from two woodblocks were selected, where the Chinese characters "月" (meaning "moon") and "字" (meaning "character") were enhanced, revealing hidden information to a certain extent. In the original digital images, the handwriting was unclear, but after enhancement, the characters became complete and legible, with strokes extended to some degree.



(a) (b)



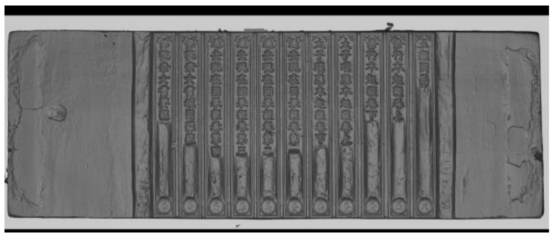
(c) (d)

Figure 7. enhanced handwriting image(a) Digital image of Handwriting on Xiang 8-10-03; (b) Image Enhancement of Handwriting on Xiang 8-10-03; (c) Digital image of Handwriting on Xiang 8-10-04; (d) Image Enhancement of Handwriting on Xiang 8-10-04

3.2 Virtual Damage Restoration

Due to the woodblocks being damaged by various afflictions, the most common damages on woodblocks are cracks and defects. To restore the original appearance of the woodblocks, we improve the patch-based algorithm for their restoration. As shown in Figure 8, the images depict the Bi-Qian woodblock before and after restoration. Figure 8(a) is the unrestored image of the Bi-Qian woodblock, and Figure 8(b) shows the woodblock after restoration. It can be observed that virtual restoration has been performed on the woodblock to a certain extent, repairing surface damages such as cracks and defects.

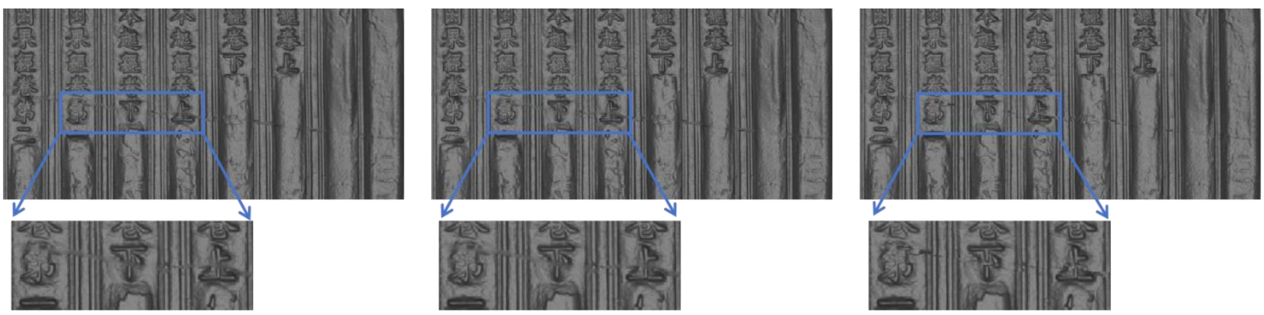
(a)



(b)

Figure 8. Virtual repair of Bi-Qian woodblocks(a)Before Restoration; (b) After Restoration

To verify the effectiveness of the algorithm proposed, partial images of the woodblocks were intercepted. The algorithm in this paper (Figure 9(c)) was compared with CDD (Figure 9(a)) and FMM (Figure 9(b)). Through the comparison between the proposed algorithm and other algorithms, it is found that the proposed algorithm demonstrates improvements in text restoration at the positions shown in the figure, particularly in the restoration of line structures. The other two algorithms produce blurred line restoration. Furthermore, the overall restoration of the proposed algorithm has higher correlation with the background, while the restorations of the other two algorithms are less smooth.



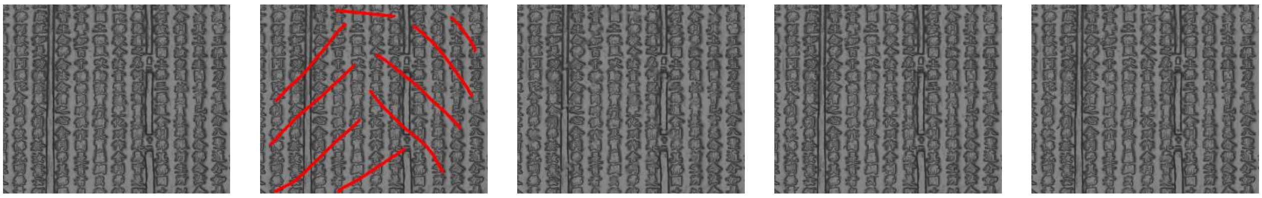
(a) (b) (c)

Figure 9. Comparison of repair algorithms(a) CDD algorithm; (b) FMM algorithm; (c) algorithm proposed in this paper

To further evaluate the algorithm, this paper uses undamaged woodblocks as the evaluation object. Simulated cracks are created artificially in undamaged woodblocks shown in Figure 10(b), and then image evaluation metrics is used to verify the

https://doi.org/10.5194/isprs-archives-XLVIII-M-9-2025-919-2025

algorithm's superiority. Figure 10 demonstrates the restoration of artificially damaged woodblocks using different algorithms. It can be seen that the algorithm proposed in this paper exhibits the best visual restoration effect. The CDD algorithm (Figure 10(c)) performs worse than the other two algorithms in restoring structural lines, resulting in discontinuous restoration near characters and other lines, blurred repairs, and obvious restoration traces. The Criminisi algorithm (Figure 10(d)) shows better line structure restoration than FMM, but it has the problem of repair mismatch, leading to obvious incomplete restoration. Compared with the previous two algorithms, the proposed algorithm shows significant improvements in restoration effect, particularly in the restoration of character line structures and reduction of restoration traces



(a) (b) (c) (d) (e)

Figure 10. Comparison of different algorithms for repairing simulated murals(a) Original Image; (b) Simulated Damage Image; (c) CDD algorithm; (d)criminisi algorithm; (e) algorithm proposed in this paper

Finally, we use three metrics of Peak Signal-to-Noise Ratio (PSNR), Structural Similarity (SSIM), and Mean Squared Error (MSE) to objectively evaluate the restoration results of woodblock images. By comparing with the original woodblock images, the effects of three restoration algorithms were evaluated. The relevant PSNR, SSIM, and MSE parameters are shown in Table 1. As Table 1 indicates, compared with the CDD algorithm and Criminisi algorithm, the proposed algorithm demonstrates improvements in both PSNR and SSIM values, indicating higher quality of the restored images and better restoration of structural information. Meanwhile, the MSE value is significantly reduced, suggesting smaller errors and more accurate restoration results.

Valuation Metrics	CDD	Criminisi	The Paper
PSNR	32.94	34.03	34.21
SSIM	0.957	0.969	0.971
MSE	33.25	25.90	24.79

Table 1 Accuracy evaluation of different results

4. Conclusion

In this paper, we propose a method to protect ancient woodblocks using digital technologies, employing hyperspectral imaging and close-range photogrammetry for their preservation and restoration. Aiming to extract information from woodblocks and repair damages, we leverage hyperspectral technology's strong penetrability and multi-band characteristics to extract hidden information, while using image restoration methods in close-range photogrammetry to address woodblock damages. To explore more information, we combine digital techniques LIME and dark-channel methods with hyperspectral technology to mine concealed details. Experiments show that the proposed algorithm effectively reveals side text on woodblocks. Facing aesthetic damages like cracks and defects, we introduce an improved patch-based algorithm for digital image restoration. Comparisons with other algorithms demonstrate that the improved method achieves better structural information restoration and higher precision.

Acknowledgements

This research was supported by the National Natural Science Foundation of China (No.42171356，No.42171444).

References

Alsadik, B., Abdulateef, N.A., &Khalaf, Y.H., 2019. Out of plumb assessment for cylindrical-like minaret structures using geometric primitives fitting. *ISPRS International Journal of Geo-Information*, 8(2): 64.

Chen, Y., Liu, X., Lyu, S., Wu, W., &Wang, R., 2022. Method of hidden strip information extraction from hyperspectral images of ancient paintings. *Sensors and Materials*, 34.

Dai, R.C., Huan, T., Bin, T., 2022. Study on Detection Method of Foxing on Paper Artifacts Based on Hyperspectral Imaging Technology. *Spectroscopy and Spectral Analysis*,42(5): 1567-1571.

Gao, Z., Du, M., & Cao, W.L.S., 2023. Application of hyperspectral imaging technology to digitally protect murals in the qutan temple. *Heritage Science*, 11(1).

Gao, Yu., Sun, X.J., Li, G.H., Zhang, L.F., Qu, L., & Zhang, D.H., 2024. Recognition of Hidden Inscriptions on Ancient Calligraphy Relics Based on Hyperspectral Technology. *Spectroscopy and Spectral Analysis*, 44(12), 3485-3493.

Kang, G., 2009. The Artistic Style of Wooden Block Carving Craft for Tibetan Buddhist Scriptures. *Religious Studies*, (01): 171-175.

Yao, F., 2019. Damaged region filling by improved criminisi image inpainting algorithm for thangka. *Cluster Computing*, 22(6), 13683-13691.

Wang, H., Li, Q., Zou, Q., 2019. Inpainting of Dunhuang murals by sparsely modeling the texture similarity and structure continuity. *Journal on Computing and Cultural Heritage*, 12(3): 1-21.

Zhang, L.F., Wang, S., Zhang, Y., Yuan, DS., Song, RX., Qi, W. C., ... & Tong, Q. X., 2023. Progress of hyperspectral remote se nsing applications on cultural relics protection. *Acta Geodaetica et Cartographica Sinica*, 52(07), 1126-1138.

Zhao, X., 2023. Overview of the Value of Block Printing of the *Qianlong Tripitaka* Woodblocks in the Collection. *A Collection of Essays about Capital Museum of China*, (00), 169-176.