



# Calligraphy in the Digital Age: Addressing Distortion and Enhancing Cultural Heritage

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**Abstract.** As the global art landscape transitions toward digital transformation, calligraphy, a significant element of traditional Chinese art, should actively embrace this evolution. However, existing digital calligraphy tools encounter significant challenges in both technical expressiveness and cultural transmission. A key issue is the distortion of details, which compromises stroke fidelity and erodes the cultural essence of the art form. This, in turn, hampers the promotion of digital calligraphy in education and the preservation of its cultural values. This study aims to comprehensively examine the distortion issues in calligraphy digitization, identify their technical and cultural origins, and offer specific recommendations for improvement. By exploring technological advancements and strategies for cultural transmission, this study seeks to improve the functionality of digital calligraphy tools and facilitate their broader adoption in modern society. Through a literature review, this study identifies four primary categories of distortion in digital calligraphy tools: stroke distortion, visual distortion, data collection distortion, and cultural transmission distortion. Building on this framework, the study proposes actionable strategies to enhance technical tools and improve the effectiveness of cultural transmission.

**Keywords:** Calligraphy digitization, distortion phenomenon, cultural heritage, technology optimization

## 1 Introduction

With the rapid advancements in technologies like virtual reality (VR), augmented reality (AR), and three-dimensional (3D) modeling, art digitization is emerging as a significant global trend. Calligraphy, a central pillar of traditional Chinese art, is also embracing digital transformation. Digital calligraphy reflects technological advancements and integrates cultural significance through interdisciplinary research, creating new opportunities for the modernization and international promotion of calligraphy. However, many technical challenges persist in the digitization of calligraphy, especially in restoring stroke fidelity, representing ink tonal gradations, and capturing brushstroke dynamics. These technical shortcomings result in notable distortions in digital representations, diminishing the artistic integrity and cultural legacy of calligraphy. This paper addresses the prevalent distortion issues in calligraphy digitization,

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P. P. Ng et al. (eds.), *Proceedings of the 2025 10th International Conference on Modern Management, Education and Social Sciences (MMET 2025)*, Advances in Social Science, Education and Humanities Research 961, [https://doi.org/10.2991/978-2-38476-475-4\\_2](https://doi.org/10.2991/978-2-38476-475-4_2)

systematically classifies the types of distortion in digital tools, establishes a preliminary analytical framework, and examines their technical and cultural origins. By proposing practical technical optimizations and strategies for cultural transmission, this study aims to advance the preservation and innovative development of calligraphy in modern society.

## 2 Current State of Research and Methodology of this Paper

The academic field has explored the issue of calligraphy digitization from various perspectives. This paper categorizes related research into two groups—Chinese and English literature—and conducts a comparative analysis. By systematically collecting and reviewing Chinese and English studies on digital calligraphy tool iterations, algorithm updates, distortion phenomena, and cultural transmission, this paper establishes a theoretical and data-driven foundation for understanding the current research landscape. By deeply analyzing quantitative technical evaluation data and qualitative user feedback from these studies, this paper identifies distortion issues in existing digitization tools, formulates a systematic classification framework for these distortions, and proposes strategies for technical optimization and enhanced cultural transmission.

### 2.1 Research Status in Chinese Literature

An analysis of the Chinese literature reveals that most studies focus on the role of calligraphy digitization in education and cultural promotion. For instance, many explore how digital technology improves access to calligraphy education or mitigates disparities in educational resources. However, these studies largely remain at the theoretical discussion stage and lack specific technical solutions for optimizing digital tools. For instance, Xu's[1] study analyzes students' subjective evaluations of using virtual brushes for calligraphy practice, while Hou [2] emphasizes the risk of cultural core erosion in calligraphy as the level of digitization deepens. These studies provide empirical evidence for the categorization of "stroke distortion" and "cultural distortion." However, they fall short of offering concrete strategies to address the existing technical issues in digital calligraphy tools.

### 2.2 Research Status in English Literature

In contrast to the Chinese literature, which emphasizes theoretical discussions, the English literature takes a more quantitative approach, focusing on evaluating the technical performance of digital tools in areas like 3D modeling, augmented reality (AR), and virtual reality (VR). For instance, Jian et al.[3] examined methods for reconstructing traditional calligraphy works using ICP algorithms, assessing both their precision and artistic quality. Gao[4] presents comparative data on the accuracy of different digital tools in simulating calligraphic strokes and evaluates their capability to minimize distortion. The English literature primarily focuses on assessing these tools' ability to simulate the dynamic process of calligraphic strokes, with quantitative

experimental results showcasing their precision, stroke reproduction accuracy, and smooth handling of calligraphic fluidity.

### **2.3 Research Gaps and Shortcomings**

Existing Chinese literature primarily focuses on the educational function of digital calligraphy but lacks in-depth exploration of the technical aspects. Conversely, English literature emphasizes technological innovation but pays less attention to the cultural connotations of calligraphy. Moreover, neither body of literature effectively bridges technical research with the cultural heritage of calligraphy, nor do they offer systematic classification and analysis of distortion issues in digital calligraphy. By systematically categorizing these distortions, this paper explores innovative pathways for integrating technology and culture, offering a theoretical foundation for optimizing digital calligraphy tools and proposing actionable strategies for the modernization and preservation of calligraphic heritage.

### **2.4 Methodology**

This paper employs literature analysis to systematically review and evaluate studies on digital calligraphy from both domestic and international sources, identifying distortion phenomena and assessing their impact. During the literature collection and screening process, the study focuses on core research related to digital calligraphy tools, technological distortion, and cultural transmission. By synthesizing scattered descriptions of distortion phenomena in the literature, the paper constructs a systematic categorization framework and provides actionable recommendations for improvement.

## **3 Findings and Discussion**

Based on the literature review, this paper develops an analytical framework for digital calligraphy distortion, classifying it into four categories: stroke distortion, visual distortion, data collection distortion, and cultural transmission distortion. This framework reveals the performance limitations of current technical tools and identifies core challenges in cultural transmission, providing guidance for future technical improvements and cultural preservation efforts.

### **3.1 Classification and Analysis of Distortion**

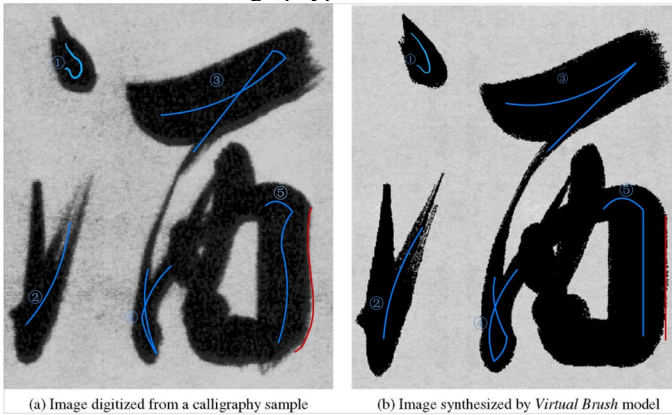
#### **3.1.1 Stroke Distortion.**

Stroke distortion is a significant issue in calligraphy digitization, arising from the difficulty of accurately capturing the nuanced brush movements with current technologies. For instance, many digitization tools struggle to replicate essential techniques like "lifting and pressing" and "turning," which are affected by factors such as light interference, the similarity between brush and ink colors, the number of brush

hairs, and irregular movement patterns. This challenge is particularly pronounced when replicating complex scripts such as running script and cursive script. Additionally, the data collection for certain calligraphic styles remains limited, predominantly focusing on the works of calligraphers such as Liu Gongquan and Yan Zhenqing. Tools often fall short when addressing the works of calligraphers known for their varied brush techniques, including Zhong Yao, Wang Xianzhi, and Chu Suiliang.

Wong and Ip's[5] research demonstrates that virtual brush algorithms have significantly enhanced the simulation of brush writing but still present issues of stroke distortion. For example: Stroke paths in examples ① ② and ④ are either oversimplified or diverge notably from the original. This may result from the virtual brush's inability to mimic the simultaneous and uneven ink flow characteristic of real brushes. In example ③, the brush path restoration is inaccurate. When completing a horizontal stroke, the brush typically reaches its maximum flexibility, requiring "lifting" and "changing the brush angle" to produce finer lines in subsequent strokes. This process is often misrepresented in virtual brush-generated characters, likely due to incorrect ink accumulation. Example ⑤ demonstrates an overly simplified stroke path, missing the "lifting" and "tucking inward" movements of the original. This results in strokes that appear lifeless and lack the vitality of traditional calligraphy.

The discrepancies are illustrated more intuitively by comparing the red outline with the virtual brush-generated results. While these differences may seem subtle and imperceptible to beginners or entry-level practitioners, the essence of calligraphy—its "rhythmic quality" and "intrinsic charm"—lies in these delicate details. If stroke distortion cannot be further optimized, the digitization of calligraphy risks losing its unique "rhythmic quality" and cultural attributes. Figure 1 is the virtual brush: a model-based synthesis of Chinese calligraphy.



**Fig. 1.** Virtual brush: a model-based synthesis of Chinese calligraphy[5]

### 3.1.2 Visual Distortion.

Visual distortion is mainly evident in the inadequate rendering of ink color intensity and gradation. While virtual brushes can mimic some aspects of ink gradation, they are significantly inferior to the natural tonal variations created by a traditional

brush on rice paper, especially in capturing the dynamic interplay of ink. This distortion significantly undermines the overall artistic expression of calligraphy in digital tools. Li[6] pointed out that current virtual tools struggle to replicate the natural variations in ink dryness, wetness, and thickness. The "character structure," "composition," and "ink technique" are the three fundamental components of Chinese calligraphy, all of which are indispensable. Similarly, Luo[7] emphasized that the limitations of current technical tools prevent virtual calligraphy from reflecting subtle variations in ink, thereby neglecting the essential "ink technique." This deficiency results in a dull and oppressive appearance of the characters, resembling computer-generated text and lacking the intrinsic aesthetic appeal of calligraphy. To address this issue, future advancements in optical imaging and dynamic simulation technologies, combined with 3D modeling tools, will be key directions for optimizing and reducing visual distortion. Figure 2 is learning Chinese calligraphy in VR WithSponge-Enabled Haptic feedback

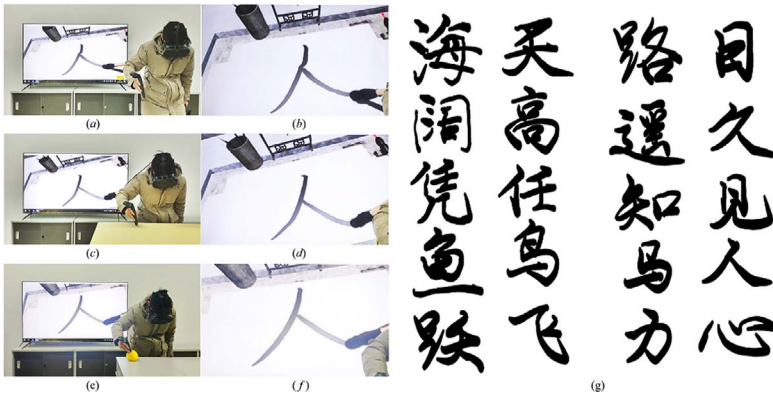


Fig. 2. Learning Chinese Calligraphy in VR WithSponge-Enabled Haptic Feedback[7]

### 3.1.3 Data Collection Distortion.

Data collection distortion primarily manifests in the narrow scope of data sources and the imprecision of input processes in technical tools. Current data collection predominantly focuses on static images, which hampers the effective capture of the dynamic writing process and limits the capabilities of digitization tools. The ICP algorithm proposed by Jian offers a more accurate restoration of the original appearance of calligraphy. However, while the algorithm demonstrates significant potential, it remains limited in its ability to capture the diversity of calligraphic styles. Integrating existing technologies and datasets could greatly accelerate the development and refinement of a comprehensive calligraphy cloud platform.

### 3.1.4 Cultural Transmission Distortion.

One major cause of cultural transmission distortion is the inability of digital tools to effectively convey the spirit of calligraphy. Research shows that current digitization efforts primarily focus on reproducing calligraphy strokes at a technical level, often neglecting the cultural connotations inherent in the art form. This issue is com-

monly reflected in user feedback: while users can replicate the form of calligraphy strokes using digital tools, they often struggle to grasp the "spirit and cultural depth" of calligraphy. To address this, the study proposes several strategies for improvement: first, integrate cultural background explanations with technological enhancements, enabling users to gain a deeper understanding of the cultural value of calligraphy through multimedia interaction. Second, establish a comprehensive calligraphy data cloud platform by integrating existing technologies, consolidating data from various collection methods for broader application. This platform could support offline calligraphy teaching, allowing instructors to integrate cultural knowledge into lessons and deepen learners' appreciation of calligraphy's cultural value. Finally, use modern media technologies to enhance the visibility of calligraphy and attract a broader audience. This would help raise awareness and deepen public interest in calligraphy, fostering a more profound understanding of its cultural significance. By implementing these strategies, digital calligraphy tools can improve not only in technical precision but also in cultural transmission, ensuring that the art's cultural richness is preserved and appreciated.

## **3.2 Recommendations for Technical Improvements**

### **3.2.1 Various Types of Distortion.**

To reduce stroke distortion, it is recommended to implement a high-precision pressure sensor or refine the pressure sensor model, enabling the virtual brush to accurately capture nuanced brush movements, such as "lifting and pressing" and "changing directions." Additionally, optimizing the algorithm model can further enhance the simulation of stroke fluidity and variations in pressure intensity. To address visual distortion, incorporating an advanced pressure sensor combined with a dynamic fuzzy logic algorithm is suggested to enhance the precision of capturing brush movements. To address ink distortion, AI technology can be integrated with dynamic simulation capabilities in 3D modeling to more accurately replicate the fluid dynamics of ink in calligraphy. AR/VR technology can recreate the dynamic process of calligraphy creation through immersive experiences, enabling users to directly observe the evolving dynamics of calligraphy.

### **3.2.2 Optimized Path of Cultural Transmission.**

The cultural transmission of digital calligraphy must be supported by modern communication tools and interactive design. Short videos and gamification are effective modern communication methods, integrating calligraphy culture into media formats familiar to the public through creative and engaging content design. For example, the recent game *Black Myth: Wukong*[8] successfully captured public attention through its innovative use of calligraphic elements, serving as a typical example of cultural promotion.

Interactive features, such as multimedia introductions to the historical origins and cultural background of calligraphy, can help users gain a deeper understanding of its spiritual essence. Integrating existing technologies to establish a calligraphy data cloud

platform can standardize and streamline access to calligraphy learning resources, further facilitating the promotion of digital calligraphy.

## **4 Theoretical and Practical Significance of this Paper**

### **4.1 Theoretical Implications**

This paper categorizes distortion issues into four major types: stroke distortion, visual distortion, data collection distortion, and cultural transmission distortion. This systematic classification addresses the gap in existing research and establishes a framework for future technological optimization and cultural transmission.

Compared to existing literature, which primarily focuses on technical details or the digitization of a single calligraphic style, this study adopts a combined technological and cultural perspective, highlighting the unique role of calligraphy as both an art form and a cultural medium. By revealing the technological roots and cultural influences behind the distortion phenomenon, this study opens up new research directions for interdisciplinary fields such as computer science and art education.

Additionally, most current research on calligraphy digitization emphasizes improving visual clarity, while exploration of its cultural significance remains limited. This study, for the first time, identifies cultural transmission distortion as a significant category, offering a theoretical foundation for future research on restoring the essence and cultural depth of calligraphy through technology. This perspective lays a solid theoretical foundation for addressing the problem of cultural loss in the digitization of calligraphy.

### **4.2 Practical Implications**

The significance of calligraphy digitization is not only reflected in technological progress but also in its positive contribution to educational equity and cultural transmission. By categorizing and analyzing distortion phenomena in digital calligraphy, this study proposes a specific path to optimize technology and improve cultural transmission.

Digital calligraphy tools can significantly lower barriers to entry and reduce the reliance of traditional calligraphy education on instructors and physical settings. By establishing a comprehensive calligraphy cloud platform, even learners in remote areas can access high-quality calligraphy courses through distance education. When combined with AR/VR technology, digital tools can simulate the guidance of a master teacher, helping learners grasp calligraphy skills more directly and overcome the traditional challenge of "self-learning difficulty."

Digital calligraphy offers more possibilities for integrating traditional art into modern media. For example, showcasing the creative process or cultural background of calligraphy on short video platforms can effectively engage young audiences; incorporating calligraphic elements into game design and cultural products can further amplify its reach and appeal. This combination helps overcome the barriers of callig-

raphy as a "high-entry" art, enabling more people to understand and appreciate its artistic value.

Digital calligraphy can better preserve valuable historical calligraphic works, especially in cases where the originals are lost or damaged, by leveraging 3D modeling and dynamic reproduction technology to restore intricate details and the essence of ink and brushwork. Furthermore, by capturing the real-time creative process of contemporary calligraphers and archiving it on a cloud platform, digital calligraphy not only safeguards artistic heritage for future generations but also offers researchers comprehensive data resources, advancing academic research and cultural dissemination.

## **5 Conclusions and Outlook**

### **5.1 Conclusions of the Study**

Through systematic analysis, this study identifies four major distortions in digital calligraphy tools: stroke distortion, characterized by insufficient restoration of brush movement details; visual distortion, marked by inadequate representation of ink intensity and dynamic changes; data collection distortion, resulting from uniform collection standards and limitations in optical imaging technology; and cultural transmission distortion, reflected in the tools' inability to convey the spirit and cultural essence of calligraphy. These findings provide a scientific basis for the technical optimization of digital calligraphy tools.

This study proposes several technological improvements, including implementing high-precision pressure sensors to reduce stroke distortion, enhancing optical imaging technology to better represent ink color, and developing AR/VR-based tools to create immersive calligraphy experiences. Additionally, this study proposes innovative cultural transmission pathways, such as establishing a calligraphy cloud platform and leveraging modern media like short videos, to offer practical guidance for modernizing and preserving the art of calligraphy.

### **5.2 Research Limitations**

Despite the significant progress and innovations in exploring systematic classification and technological pathways, this study has certain limitations that need further refinement. First, this study is primarily based on literature analysis and lacks field tests and user feedback data. While this approach offers a theoretical foundation, it does not fully capture the practical effectiveness of digital calligraphy tools in teaching and cultural dissemination, especially the real experiences and needs of users across different contexts.

Second, the existing categorization framework mainly focuses on the combination of technical issues and user feedback, but it remains insufficient in integrating cultural psychology and educational theories. Calligraphy digitization encompasses multiple dimensions, including user learning experience and cultural perception. However,

further research is needed to explore how technical design can reduce cognitive load and improve learning efficiency.

Finally, the user feedback data in this study mainly comes from calligraphy learners and technology developers, with limited representation of broader user groups, such as beginners and cultural enthusiasts. Future studies should conduct broader user research to refine the design of digital calligraphy tools and enhance cultural promotion pathways.

### **5.3 Future Research Directions**

Future research could gather empirical data across different scenarios through field experiments and user testing to thoroughly evaluate the effectiveness of the classification framework and technological pathways. Additionally, theories from psychology, human-computer interaction, and cognitive science can be integrated to deeply analyze users' psychological experiences and learning processes with digital calligraphy tools, and to explore ways to enhance learning efficiency and cultural understanding through technological design.

In the future, deeper exploration of cultural transmission can be achieved through collaboration with cultural scholars and calligraphers, designing more immersive tools for calligraphy learning and cultural experiences using multimedia interaction, virtual reality (VR), augmented reality (AR), and related technologies. Meanwhile, the visual aesthetics of calligraphy can be further enhanced to help users gain a clearer understanding of its cultural significance. Short videos and game design can serve as key tools to promote and popularize calligraphy culture.

## **6 Conclusion**

This paper provides a systematic summary of distortion phenomena in calligraphy digitization. In terms of technological advancements, the paper proposes adopting high-precision pressure sensors, enhancing optical imaging technology, and developing AR/VR-based immersive tools. Additionally, by establishing a calligraphy cloud platform and leveraging modern media like short videos, the study introduces innovative cultural transmission pathways and promotes the modernization and preservation of calligraphy. Finally, the paper highlights the study's limitations, including the absence of field tests and user feedback data, as well as gaps in applying cultural psychology and educational theories. Future research will integrate theories from psychology, human-computer interaction, and related fields to conduct an in-depth analysis of user experiences and learning processes, and to comprehensively validate the proposed framework.

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