

# Research on the Design and Application of the “Cloud Stage Opera” Interactive Installation of Luoshan Shadow Puppetry in the Context of Digital Cultural Tourism

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## Abstract:

Against the backdrop of the in-depth integration of digital culture and tourism, Luoshan shadow puppetry — a national intangible cultural heritage of China — faces practical dilemmas including a generational gap in inheritance, an aging audience base, and monotonous presentation forms. Centering on Luoshan shadow puppetry, this study proposes a design scheme for a somatosensory interactive installation built on the dual-engine integration of Unity and TouchDesigner. By sorting out the artistic features and inheritance status of Luoshan shadow puppetry, the study establishes the design principle of preserving cultural authenticity + innovating immersive interaction, and constructs a technical architecture where “TouchDesigner (TD) handles real-time visual effects and sensing data processing, while Unity manages 3D scenes and character interaction logic”, so as to realize data intercommunication and visual fusion between the two engines. Research shows that this interactive installation can break the one-way communication mode of traditional shadow puppetry — “performance on stage, passive viewing off stage” — and enable audiences to directly participate in shadow puppetry performances through somatosensory control. While retaining the aesthetic style and cultural core of Luoshan shadow puppetry, it significantly enhances the sense of participation and immersion in cultural tourism scenarios, providing a replicable technical path and design paradigm for the living inheritance of intangible cultural heritage and the innovation of digital cultural tourism.

## Keywords:

Digital Cultural Tourism, Luoshan Shadow Puppetry, Sensory Interaction

## 1. Introduction

With the in-depth implementation of the 14th Five-Year Plan for Cultural and Tourism Development issued by the Ministry of Culture and Tourism of China, digital technology has become the core driving force for the revitalization of intangible cultural heritage (ICH) and the integration of culture and tourism. As the core carrier of regional culture, ICH can no longer meet the experiential demands of contemporary tourists with its traditional exhibition methods. How to realize the creative transformation and innovative development of ICH by means of digital

interactive technology has become a key research topic in the field of digital cultural tourism.

Luoshan shadow puppetry originated in Luoshan County, Xinyang City, Henan Province, and was inscribed on the second batch of the National Intangible Cultural Heritage List in 2008. Taking the “Cloud Stage Opera” of Luoshan shadow puppetry as the creative theme, this study adopts a technical route combining Unity and TouchDesigner (hereinafter referred to as TD) to design and develop an immersive interactive installation. The study aims to address three core issues:

- (1). How to preserve the cultural authenticity of Luoshan shadow puppetry in digital transformation;
- (2). How to achieve high-quality real-time interaction and visual presentation through dual-engine technology integration;
- (3). How to organically integrate interactive installations with digital cultural tourism scenarios to achieve a win-win outcome between ICH inheritance and cultural tourism value.

## **2. Related Concepts and Research Foundation**

### ***2.1. Digital Cultural Tourism and ICH Revitalization***

Digital cultural tourism is the product of the deep integration of digital technology and cultural tourism. Its core feature is to enhance the immersion, interactivity and personalization of tourism experiences through digital means. ICH revitalization refers to endowing ICH with new forms of expression and application scenarios via modern design and technology on the premise of protecting its cultural core, so that it can be integrated into contemporary life.

However, most existing studies rely on a single technical engine, making it difficult to balance the complexity of real-time visual effects and the richness of interaction logic. Existing digital research on Luoshan shadow puppetry mostly focuses on VR restoration and digital communication, while research on dual-engine integration design for on-site interactive installations remains absent. This gap constitutes the innovative entry point of this study.

### ***2.2. Technical Foundation of Unity-TD Integration***

As a mainstream 3D interactive engine, Unity boasts strengths in powerful physics systems, character skeletal animation, complex interactive logic development and cross-platform deployment. It is suitable for building shadow puppetry characters and 3D scenes and implementing interaction logic. TD, by contrast, is a node-based programming tool dedicated to real-time audio-video processing and visual generation. It excels in particle effects, lighting rendering and real-time sensor data processing, and is ideal for creating dynamic visual effects for shadow puppetry.

The integration of the two engines is realized through three main technical paths:

- (1). OSC protocol for control data transmission: TD processes somatosensory sensor data and sends it to Unity to drive the movement of shadow puppetry characters.
- (2). Spout/NDI protocol to transmit video streams, and superimpose the effects generated by TD onto the rendering screen of Unity in real time.

(3). Unified coordinate system conversion: Resolving the coordinate system difference between Unity (Y-axis upward) and TD (Z-axis upward).

This dual-engine architecture balances interaction depth and visual quality, making it more suitable for creating ICH interactive installations than single-engine solutions.

### **3. Design Strategies of the “Cloud Stage Opera” Interactive Installation**

#### ***3.1. Design Principles***

In the design practice of the digital interactive installation of Luoshan shadow puppetry, the dual core of cultural dynamic inheritance and cultural tourism value transformation has always been the guiding principle. The systematic design principles have been followed to advance all work. The authenticity of culture is the primary underlying principle. Throughout the design process, the original shaping rules, color system and performance procedures of Luoshan shadow puppetry were strictly adhered to. The singing voice and accompanying sound effects all adopted the original recordings of the intangible cultural heritage inheritors. Digital technology was only positioned as a carrier and auxiliary means for cultural presentation, and technological showmanship was completely avoided to prevent the disintegration of the cultural core of shadow puppetry art by technical display. The layering of experience is the core logic of content construction. By building a gradient experience content framework, covering three experience dimensions of viewing perception, interactive operation and creative creation, it can adapt to diverse audiences of different age groups and different cognitive levels. The adaptability of scenes is an important guiding principle for implementation and promotion. It fully considers the spatial conditions and actual operational needs of different cultural tourism scenarios, provides multiple forms of implementation solutions, and at the same time, reasonably controls the project construction cost and the difficulty of later operation and maintenance. The moderation of technology is the basic criterion for technology selection. The priority is to choose mature, stable and cost-effective technical paths. The core evaluation criteria are the smoothness of user experience and the effectiveness of cultural transmission. Blind pursuit of cutting-edge technologies is avoided to prevent deviation from the core goal of cultural communication of the project.

#### ***3.2. Overall Design Framework***

Constructing the overall design framework of "one machine with three modes": Using the digital cloud platform as the unified physical carrier, it is equipped with three interactive forms: performance mode, experience mode, and co-creation mode, corresponding to the three cultural logics of "view - perform - create" in traditional shadow puppetry. The digital cloud platform restores the visual image of the traditional high platform, retains a height of about 1.5 meters for the shadow window and the classic aspect ratio, continues the traditional sense of ceremony, and integrates display, capture, audio, and interaction systems to form an integrated digital shadow puppet stage.

#### ***3.3. Design of Layered Interaction Modes***

Exhibition mode (Digital Cloud Stage Theater): Targeted at casual tourists with short stay times. Classic excerpts from operas such as Generals of the Yang Family

and Investiture of the Gods are selected, each lasting 3–5 minutes. Inheritors' performances are restored via motion capture and keyframe animation, paired with original singing and accompaniment. Rear projection or high-definition displays simulate the translucent texture of kraft paper shadow windows. The system supports automatic carousel and touch on-demand playback, and automatically runs demonstration content to attract visitors when idle.

Experience mode (Somatosensory Shadow Puppetry Control): The core mode of the installation. The traditional “three-rod” control logic is translated into natural somatosensory movements: arm translation corresponds to lateral movement of the shadow figure, arm lifting corresponds to bowing gestures, arm waving corresponds to fighting movements, and body rotation corresponds to the figure turning around. Simple plot levels with action prompts and target guidance are set up. Two players can operate different characters simultaneously to perform rival scenes, enhancing sociality and entertainment, and allowing audiences to grasp the logic of shadow puppetry performance through gamified experience.

Co-creation mode (Digital Shadow Puppetry Workshop): Allows users to participate in character design. A built-in library of classic Luoshan shadow puppetry patterns enables users to generate personalized characters through touch selection and matching. The system automatically complies with modeling rules and color specifications to ensure results conform to Luoshan shadow puppetry aesthetics. Customized characters can be imported into the experience mode for a “premiere”. After the experience, an exclusive commemorative card is generated, which can be saved via QR code and shared on social media to form secondary communication.

### ***3.4. Multi-Scene Adaptation Schemes***

Based on the principle of scene adaptability, the research aims to construct three differentiated installation solutions based on the spatial characteristics, target audience groups and operational goals of different application fields, thereby forming a diversified and adaptable system covering public culture, tourism and cultural consumption, and campus education.

Museum scenario: Standard fixed installations with full three modes and rich repertoires, paired with professional docents. Form an exhibition combination of “physical artifacts + interaction” with tangible shadow puppetry exhibits, fulfilling the function of cultural education.

Tourist attraction scenario: Modular weather-resistant design with simplified content, highlighting the somatosensory experience mode, shortening single-user experience time to improve passenger turnover, and embedding scenic cultural nodes to extend visitor stay time.

Campus public education scenario: Lightweight desktop installations focusing on teaching and experience functions, supporting knowledge courseware and creation tools for aesthetic education courses and cultural activities.

## **4. Design and Implementation of the “Cloud Stage Opera” Interactive Installation**

### ***4.1. Preliminary Material Collection and Sorting***

The collection of materials is divided into two categories: cultural materials and technical materials. In terms of cultural materials, field research was conducted at the Puyin Opera Training Institute in Luoshan County, the Folk Culture Village, and the County Cultural Center. High-definition photos of various characters including male, female, ugly and beautiful were taken, and the structural patterns and color parameters of the patterns were recorded. The performances of the inheritors of classic plays were recorded, and sound effect materials such as singing, speaking, gongs, and flutes were collected. Interviews with the inheritors were conducted to sort out the performance action procedures and control logic. In terms of technical materials, the model and parameters of the body-sensing camera were confirmed, the recognition accuracy under different lighting conditions was tested, and the parameters of the display screen and the hardware computing power requirements were confirmed. After the collection was completed, a visual and sound material library for Luoshan Puyin Opera was established. Design parameters such as styling norms, color values, and action patterns were extracted as the basis for production standards.

#### ***4.2. 3D Digital Content Production***

The 3D content is created based on the Unity engine and strictly follows the regulations of Luoshan shadow puppetry art. The character modeling is created according to the rule of "large head and small body, wide shoulders and narrow waist", creating four types of basic characters. The polygon structure is used to simulate the flat attributes of shadow puppets, the detailed patterns are restored according to the vector of the actual shadow puppets, the material settings include semi-transparency and self-illuminating properties, and the parallel light at the back is used to simulate the light transmission effect of the cowhide. The colors strictly correspond to the measured color values of the five-color system. The scene props restore traditional elements such as the stage, curtain, tables, chairs, and weapons. The dark background highlights the main figure of the shadow puppet.

The skeletal animation binds 11 skeletal joints to each shadow puppet, corresponding to the knot structure of traditional shadow puppets. A basic action library for walking, standing, bowing, fighting, and turning is created. Keyframe animation is used to ensure the accuracy of the movements, and the mixed tree technology is used to achieve smooth transitions between actions, avoiding abrupt jumps.

#### ***4.3. Development of Cross-Engine Interactive System***

The interactive system adopts a TD+Unity cross-engine collaborative architecture, with data transmitted via the OSC protocol.

**TD side:** Responsible for full-link processing of somatosensory data. It connects to the somatosensory camera to obtain joint coordinates, filters jitter data via low-pass filtering, establishes mapping rules from limb movements to shadow puppetry movements, and sends processed control commands to Unity.

**Unity side:** Responsible for scene rendering and logic implementation. It receives and parses commands from TD into character driving parameters, controls skeletal movements via the animation controller, and keeps response latency within 100ms. Gamified logic such as plot triggering and level judgment is written in C# to implement UI interactions including mode selection and repertoire switching.

In the cross-software debugging stage, motion mapping sensitivity and judgment thresholds are repeatedly optimized to ensure smooth and precise control. Meanwhile, model polygon counts are reduced and the rendering pipeline is optimized for performance, ensuring long-term stable operation of the installation.

#### ***4.4. Hardware Integration and Deployment***

Standard hardware configuration:

65-inch high-definition display, or short-throw projector + translucent screen to simulate the shadow window effect;

Kinect Azure depth camera mounted above the shadow window, with a recognition distance of 1.5–3 meters;

High-performance industrial control host running dual systems;

Hidden stereo sound system;

Wooden + steel high-stage structure, with a total height of 2.2 meters and a shadow window center height of 1.5 meters, restoring the form of the traditional cloud stage.

In terms of deployment, the installation supports local operation and cloud content updates, and is equipped with auto-start and system restore functions to reduce operation and maintenance difficulty. It also supports operation data statistics, facilitating operators to analyze usage and optimize content.

### **5. Application Value and Prospect**

#### ***5.1. Value for the Living Inheritance of ICH***

The “Cloud Stage Opera” interactive installation provides a new carrier for the inheritance of Luoshan shadow puppetry. On the one hand, it digitally preserves the essence of Luoshan shadow puppetry’s shapes, singing and repertoires permanently, breaking through the limitations of perishable physical shadow puppets and the advanced age of veteran artists. On the other hand, it lowers the learning threshold of shadow puppetry performance: audiences can experience the fun of shadow puppetry control without long-term training, which helps stimulate teenagers’ interest in ICH and expand the base of inheritors. Compared with the traditional master-apprentice inheritance system, the interactive installation realizes a positive transmission path of experience – cognition – affection – inheritance, serving as a beneficial supplement to the productive protection of ICH.

#### ***5.2. Economic Value of Digital Cultural Tourism***

In cultural tourism scenarios, the installation can effectively enhance the attractiveness of cultural attractions and extend visitor stay time. Compared with static displays, interactive experiences are more likely to trigger social sharing among tourists and generate secondary communication. The installation can derive diversified business formats such as cultural and creative products, digital collections and research-based learning courses, helping Luoshan shadow puppetry transform from a “viewing-type” ICH into an “experience-type” cultural tourism IP.

#### ***5.3. Limitations and Optimization Directions***

This research still has certain limitations. Future studies can be carried out from multiple dimensions for deepening and expansion. AI action generation technology can be introduced to build a training data set based on the real performance actions of intangible cultural heritage inheritors. Through the generation model, the puppet show action library can be intelligently expanded to restore the delicate techniques and dynamic expressiveness of traditional performances. A lightweight mobile terminal interactive version can be developed to break the spatial and venue limitations of physical devices, further expanding the dissemination coverage and public reach of Luoshan shadow puppetry digital culture. Moreover, the digital translation and interactive reconstruction of classic puppet shows in Luoshan can be continuously advanced, gradually forming a systematic and series-based interactive content matrix, and consolidating the content foundation of digital inheritance of intangible cultural heritage.

#### ***5.4. Promotion and Application Prospects***

The Unity-TD dual-engine integration technical scheme has strong universality. It is applicable not only to Luoshan shadow puppetry, but also extendable to other shadow puppetry schools and even more traditional opera ICH digital transformation projects. With the continuous upgrading of the digital cultural tourism industry, immersive interactive installations will become standard facilities in ICH museums and cultural tourism scenic spots. The design framework of cultural fidelity + technological empowerment + scene adaptation proposed in this study can provide methodological reference for similar ICH digital projects, and promote the creative transformation and innovative development of fine traditional Chinese culture in the digital age.

### **6. Conclusions**

Aiming at the inheritance dilemma of Luoshan shadow puppetry in the context of digital cultural tourism, this study takes somatosensory interaction as the entry point and designs an immersive interactive installation based on Unity-TD dual-engine integration. The study verifies the feasibility and advantages of the dual-engine technical route: TD's powerful real-time visual generation capability and Unity's mature interactive development capability complement each other, enabling high-quality, low-latency somatosensory interactive experience while preserving the cultural authenticity of Luoshan shadow puppetry.

The study demonstrates that the design of ICH interactive installations must prioritize the cultural core, with technology always serving cultural expression. Rather than diluting the aesthetic features of traditional shadow puppetry with digital technology, the “Cloud Stage Opera” installation amplifies its artistic essence of “narrating through light and shadow” via digital means, allowing audiences to deeply perceive the cultural charm of Luoshan shadow puppetry through interaction. The installation not only provides a new carrier for the living inheritance of Luoshan shadow puppetry, but also injects new momentum into local digital cultural tourism development, realizing the unity of cultural value and economic value.

Follow-up research will further improve the multi-person interaction mode, enrich repertoire content, and conduct on-site deployment tests and user experience evaluations, so as to continuously optimize the cultural communication effect and cultural tourism adaptability of the installation, and help Luoshan shadow puppetry —

this precious intangible cultural heritage of humanity — glow with new vitality in the digital age.

## Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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