Exploring the Application of Touch Interaction in the Digitalization of Cultural Heritage

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Abstract: As a key expression of digital media art, touch interaction plays an important role in cultural communication and industrial innovation. This study focuses on Liaoning's industrial culture and examines how touch interaction can support its digital transformation. Industrial culture conveys symbolic values such as strength and toughness, which must be translated into immersive digital experiences that foster emotional resonance. Using a multimodal approach, this study develops a design model that integrates technological implementation with artistic expression, drawing on metaphors and narratives rooted in industrial heritage. Experimental results demonstrate that force feedback, dynamic visuals, and auditory interaction significantly enhance user immersion and cultural identity. The findings provide both a methodological framework and practical paradigm for advancing the digital transformation of Liaoning's industrial culture.

Keywords: Interaction Design; Multimodal Interaction; Digital Media Art; Industrial Cultural Heritage

1. Introduction

With the rapid growth of digital media art, touch interaction design has become an essential tool for cultural communication and experiential innovation [1]. Unlike traditional static displays, it not only fulfills basic operational needs but also expands the depth and richness of cultural expression through multimodal feedback and dynamic narrative mechanisms. In particular, touch interaction is gaining prominence in the digital transformation of local culture, becoming a focus of research in both academia and industry.

As one of the cradles of modern Chinese industry, Liaoning possesses an industrial cultural heritage rich in both material forms and symbolic meaning—embodying values such as the iron and steel spirit, strength, and innovation. These symbols document China's industrialization and serve as important carriers of regional identity. However, while traditional exhibitions and static imagery can reproduce historical forms, they struggle to provide audiences with emotional resonance and immersive experiences. Consequently, designing effective touch-based interaction systems for cultural heritage has become a pressing challenge. Hirsch et al. [2] demonstrate that interactive technology offers distinct advantages in the communication of cultural heritage.

Recent trends in cultural heritage digitization have been largely technology-driven. While 3D modeling and visual displays preserve information effectively, they often lack narrative depth and emotional impact, limiting their communicative power. Touch interaction offers a promising alternative. By enabling real-time engagement between users and digital interfaces, cultural symbols can be presented dynamically, fostering intuitive understanding and emotional recognition. Interaction becomes not only an operational process but also a vehicle for meaning-making. Nofal and Reffat et al. [3] further show that tangible interaction in museum contexts elicits deeper experiential and emotional responses compared with traditional digital displays.

This study investigates the application of touch interaction design in the digital transformation of Liaoning's industrial culture. It explores perceptual dimensions and narrative metaphors within a multimodal framework, develops strategies for integrating technology with cultural heritage, and validates the effectiveness of touch interaction in enhancing immersion and cultural communication through experiments and case studies. The overarching aim is to provide practical digitalization strategies for Liaoning's industrial culture while also contributing to the theoretical development of

touch interaction design in cultural research.

2. Related Work

The digital transformation of cultural heritage has attracted growing attention in both academia and industry. Existing research mainly addresses three aspects: the digital translation of cultural heritage, the introduction of interactive technologies, and the digital communication of industrial culture.

Early research relied on 3D modeling, virtual reality and panoramic images to reproduce the physical form of cultural heritage. Such methods are valuable in information preservation and historical reconstruction, but relatively insufficient in narrative depth and emotional expression. Taking Taiyuan Arsenal Cultural Industrial Park as an example, since its opening in 2021, it has only received 31,000 visitors, and its 3D reconstruction display ignores the workers' historical memory and spiritual value, resulting in the lack of emotional resonance of the exhibition [4].

With the development of human-computer interaction theory, scholars began to emphasize the importance of interaction in cultural experience. Multimodal interaction (including tactile, acoustic and force feedback) can significantly enhance user immersion and cognitive depth, and scholars such as Terao [5] have found that combining visual, auditory and tactile feedback in non-contact aerial display interfaces significantly improves usability compared to unimodal interfaces, which underscores the effectiveness of multimodal interaction in enhancing user experience. Some museums in China have also attempted to introduce touch interaction in their exhibitions, but most of them still remain in basic operations such as sliding and clicking, and lack deep exploration of cultural narratives.

As an important symbol of modernization, the digital transformation of industrial culture concerns both heritage protection and value reengineering. Most of the related research focuses on heritage survey and documentation, and explores the cultural connotations of industrial symbols such as "sense of power" and "collaborative spirit", but there are still deficiencies in how to present these abstract values through digital media. Liu (2020) showed that in cultural heritage displays, relying only on visual presentation has the effect of conveying information, but it is often weaker than the role of this approach in emotional connection and cultural identity [6]. The study pointed out that cultural heritage displays relying only on visual design elements often neglect the long-term stimulation and dissemination of emotions, while multisensory interactions have significant potential for promoting emotional resonance [7].

In conclusion, this study explores the value of touch interaction design in digital transformation by taking Liaoning industrial culture as an object. By combing multimodal perception and narrative metaphors, combined with field research, it proposes strategies for integrating technology and culture, and verifies its advantages in immersion experience and cultural communication with experiments and cases, aiming to provide feasible solutions for the digitization of industrial culture and expand the theoretical depth and innovative value of touch interaction design.

3. Research Methodology

This study adopts the methodological path of "theory construction-case study-experimental verification", aiming to systematically explore the application mechanism of touch interaction design in the digital transformation of Liaoning industrial culture. Specifically, it includes the following four aspects.

3.1 Theory Construction

The study starts from the ontological framework of touch interaction design, and analyzes its technological evolution and multimodal development path. Early touch interaction is limited to single operations such as clicking and swiping, but with the introduction of force feedback, sound feedback and multi-touch, its perceptual dimensions are gradually expanded, realizing the integration of visual, tactile and auditory senses. Related studies have shown that multimodal interaction can significantly enhance user immersion and cognitive depth, providing a new path for the narrative expression of cultural heritage [8,9].

Based on this, this study proposes a three-layer model of "Perceptual Reconstruction - Interactive Metaphor - Cultural Narrative":

Perceptual Reconstruction: Expanding the immersion of interaction through multimodal technology; Interaction metaphor: using touch action to correspond to the values of "power" and "precision" in industrial culture; Cultural narrative: generating historical memory and

emotional resonance during the interaction.

In order to enhance the comprehensibility of the model, a schematic diagram of the theoretical model (Figure 1) is drawn to visualize the logical relationship of the three-layer model. Among them, "Perceptual Reconstruction" realizes immersion through multimodality, "Interactive Metaphor" realizes value mapping through action symbolization, and "Cultural Narrative" produces cultural The "cultural narrative" generates cultural meaning in the process of interaction.

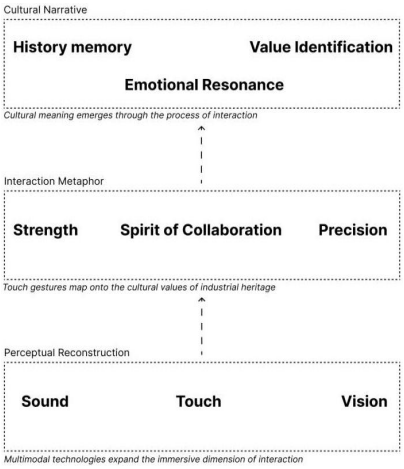

Figure 1. Three-layer Model of Touch Interaction in Cultural Digitalization

3.2 Case Studies

The research team carried out field research in a number of industrial heritage sites and museums in Liaoning, including Ansteel Museum, Shenyang Tiexi Industrial Museum and machine tool workshops. The research mainly covers:

Presentation: Current exhibitions mostly rely on static images or 3D models, lacking in-depth interaction;

User experience: the audience is able to understand the industrial process, but the emotional recognition of the spiritual connotation is insufficient;

Interaction status: some exhibition halls have used touch screens, but they mostly stay at the level of information retrieval, failing to realize immersive narratives.

In order to ensure the reproducibility of the research and the representativeness of the data, this study interviewed a total of 20 visitors and 5 experts, using a combination of semi-structured interviews and on-site observation. The research results show that the existing digital displays are more effective in information transmission, but still have significant shortcomings in experiential and cultural communication depth.

3.3 Experimental Design

On the basis of theory and research, this study constructs an experimental system centered on touch interaction, which is divided into the following three links:

System architecture: the experimental system adopts a touch screen combined with force feedback and sound feedback devices, utilizing TouchOSC(v1.2) and Unity for data transmission and real-time interaction (operating environment: Windows 10, Unity 2021.3 LTS).

Interaction Scenario: Steel smelting and gear operation are the core cultural symbols. Users can trigger visual, tactile and auditory feedback through sliding and rotating operations to experience the high temperature, pressure and mechanical resistance of the smelting process. The 3D models and animations in the experiment were built and rendered by Blender, and interactively invoked in real time through the Unity environment to ensure the realism and immersion of the visual effects.

Performance optimization: In order to solve the problem of delayed response in low-temperature environments in industrial scenarios, this study designs a delay tolerance threshold and a false-touch protection mechanism, which controls the average response of the system within 150 ms and effectively improves the interaction accuracy and operation safety.

3.4 Evaluation Indexes

The experimental evaluation is conducted in three aspects:

Immersion: Evaluate the user's immersion experience through questionnaires and on-site observation, and refer to the Immersion Experience Questionnaire (IEQ) proposed by Jennett et al. [10], which has been widely used in the research of human-computer interaction and gaming experience, and is regarded as an authoritative index for evaluating the immersion experience.

Cultural identity: analyzing whether users perceive the spiritual value of industrial culture through interaction;

Operational performance: to measure the response speed and stability of the system and test its practicality.

The experimental results were statistically analyzed using SPSS 26.0. The results show that the immersion score in the experimental group

(M=4.32, SD=0.51) is significantly higher than that in the control group (M=3.25, SD=0.47), with $t(38)=7.21$, $p<0.001$; cultural identity also shows a significant difference ($p<0.01$), which suggests that the touch interaction design can effectively enhance the user's immersion experience and cultural empathy.

4. Construction and Empirical Analysis of Touch Interaction System

This study designs and implements a touch interaction experiment based on Liaoning industrial culture to verify its immersiveness, narrativity and operability in cultural communication.

4.1 Experiments on Multimodal Touch Interface

Experiment 1 builds a multimodal touch interface with the smelting process of Ansteel as the background. Users manipulate the virtual gears and smelting equipment through the touch screen, and the system responds in real time by combining visual, auditory and force feedback. When the user swipes or rotates the screen, the interface shows the flame, metal flow and gear rotation of steel smelting, accompanied by mechanical sound and vibration feedback (Figure 2). The results show that this approach significantly enhances the user's engagement and immersion experience, and is more interactive than traditional static displays.

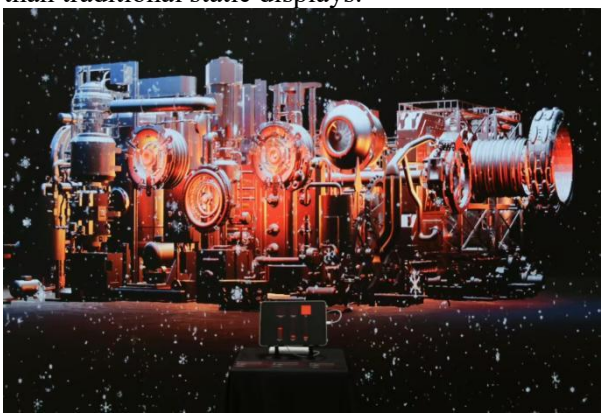

Figure 2. Multimodal Touch Interface Demonstrating the Smelting Process

4.2 Experiments on Reconstruction of Sensory Dimensions

In order to solve the delay problem of touch devices in industrial environments at low temperatures, Experiment 2 tests the response performance of the touch panel at -15°C and introduces a delay tolerance mechanism and false-touch protection strategy. The experiment uses an Arduino sensor to monitor the input signal, and the average delay of the system is stabilized within 150 ms after optimizing the algorithm. The test results show that the improved scheme significantly reduces the misoperation rate and improves the operation precision and safety. This experiment verifies the feasibility of touch interaction in complex industrial environments.

4.3 Industrial Culture Narrative and Interaction Metaphor Experiment

Experiment 3 uses the Anshan Iron and Steel blast furnace as a prototype to build a gear torque feedback platform. Users feel different strengths of resistance and vibration through touch operation, thus simulating the pressure and temperature changes in the smelting process (Figure 3). The experiment aims to reinforce the industrial spirit of "strength and toughness" through haptic metaphors. User feedback showed that the force feedback not only enhanced the realism of the interaction, but also enhanced the cognitive and emotional resonance of the symbolism of industrial culture.

Figure 3. Torque Feedback Platform Simulating Blast Furnace Operation

4.4 Experiments on the Integration of Technology and Art

Experiment 4 focuses on artistic expression. The system introduced dynamic light and sound design in the touch operation, such as the color of the flame gradually changing from orange-red to dark grey with the operation, and the steel model cooling or flowing with the interaction;

accompanied by the mechanical sound and vibration feedback, a multi-sensory narrative was formed. The feedback from users is generally that the design enhances immersion and stimulates interest in industrial culture on an aesthetic level. This suggests that the integration of technical realization and artistic expression helps to expand the space of cultural narrative.

4.5 User Experience and Result Analysis

Data were collected from 72 participants (including students, industrial practitioners, and general audiences) through questionnaires and interviews. Findings include:

Immersion: 82% reported significantly greater immersion with touch interaction compared to visual-only displays. A chi-square test confirmed this difference was statistically significant ($\chi^2=6.72$, $p<0.05$).

Cultural Identity: 76% of users recognized industrial values such as power and toughness through interaction, demonstrating stronger cultural identification.

Operational Performance: Most users found the system responsive and natural, with misoperation rates below 5%.

Collectively, the four experiments validate the advantages of touch interaction from multiple perspectives: multimodal design enhances immersion, sensory reconstruction improves operability, interactive metaphors strengthen cultural identity, and the integration of technology with art expands narrative potential. Together, these findings demonstrate that touch interaction can effectively support the digital transformation of Liaoning's industrial culture while providing a transferable model for similar cultural contexts.

5. Conclusion

This study examined the application of touch interaction design in the digital transformation of Liaoning's industrial culture through a combination of theoretical construction, case studies, and experimental verification. The findings show that touch interaction overcomes the limitations of traditional static displays by integrating visual, tactile, and auditory modalities. Through immersive engagement, users can intuitively perceive the symbolic values of industrial culture—such as power and precision—thereby deepening cultural communication and fostering emotional resonance. This mechanism not only enhances experiential depth but also provides a new methodological pathway for the regeneration and innovation of industrial heritage. Experimental results further confirm the practicality of touch interaction in complex environments. The introduction of delay tolerance thresholds and false-touch protection mechanisms ensured high precision and stability, demonstrating the system's adaptability to cultural exhibitions as well as broader industrial scenarios. Looking ahead, touch interaction is expected to evolve from isolated applications toward systematic integration. It holds the potential to play a pivotal role in revitalizing industrial culture, strengthening local cultural identity, and advancing innovation within the cultural industry.

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