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Research on Dynamic Interactive Design Strategies for Museum Exhibitions from the Perspective of Affective Computing

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Abstract

With the deepening digital transformation of museums, their development focus has shifted from the singular application of technology to the in-depth exploration of audience emotional resonance. The maturation of affective computing technology provides a new pathway for this shift. This paper aims, from a design studies perspective, to explore how affective computing can empower the dynamic interactive design of museum exhibitions. Through literature review and case analysis, a design framework comprising three core strategies—"Dynamic Narrative Reconstruction," "Adaptive Interactive Adjustment," and "Multi-Sensory Collaborative Immersion"—is constructed. This framework aims to translate emotional data into specific design parameters, promoting the evolution of museum exhibitions from static information delivery ("one-size-fits-all") to dynamic emotional dialogue ("tailored to each individual"), thereby offering theoretical reference and methodological support for the practice of "integration of art and technology."

Keywords

Affective Computing, Museum Exhibition, Dynamic Interaction, Design Strategy, Integration of Art and Technology

1. Introduction

As an important place for cultural heritage and public education, museums are undergoing a profound digital transformation. Its exhibition style is no longer satisfied with the listing and labeling of cultural relics, but seeks to build an experience space that can stimulate the audience's emotional resonance and deepen cultural cognition. In this context, affective computing, a computing technology designed to identify, analyze and respond to human emotions, provides a new technological possibility for museums to realize personalized and deep-seated interactive experience [1].

However, the current practice generally has the problem that technology is out of touch with artistic expression and emotional needs. Many digital projects may fall into "technology dazzle", with gorgeous interactive forms but vague content; Or stay in the "one-way information push" and fail to make dynamic adjustment according to the audience's real-time emotional state. The core dilemma lies in the lack of a set of design oriented methodology to systematically transform emotional computing technology into specific interaction design.

Therefore, based on the field of design, this study focuses on the following issues: how to build an effective design strategy, so that emotional computing technology can be organically integrated into the dynamic interactive design of museum exhibitions, so as to improve the emotional appeal and communication efficiency of exhibitions. This paper will then elaborate the relevant theoretical basis, construct the core design strategy, and verify its feasibility through typical situations, in order to provide innovative design ideas for the digital practice of the museum.

2. Domestic and International Research Status

The application of affective computing in museums has become an interdisciplinary hotspot, generally showing a trend of parallel development of theory and practice as well as integration of technology and humanities.

Overseas research features advanced theories and practices. Theoretically, drawing on psychological emotion assessment theories, scholars build user affective computing models combined with multimodal emotion recognition technologies (e.g., facial recognition and physiological signal detection), and have begun to pay attention to data ethics[2,3]. Practically, representative projects have emerged, including Emotion Loader at Finland's Kiasma Museum[4] which transforms visitors' facial expressions into artistic creations; Belgium's Sense Shifting project[5], which externalizes physiological signals into ambient light and shadow; and Sensitive Pictures at Norway's Munch Museum[6], which combines self-reporting and machine-based sentiment analysis to explore in-depth dialogue between audiences and artworks.

Domestic research emphasizes the combination of technologies and local cultural communication. Theoretically, most studies adopt Norman's three-level emotional design theory as the framework[7] and explore its integration with emerging technologies such as Mixed Reality (MR) and Artificial Intelligence Generated Content (AIGC)[8,9], aiming to lower the comprehension barriers of traditional culture. Practically, AI digital human docents and "emotion recognition + dynamic content adaptation" constitute two major directions. By analyzing users' emotions, personalized guided tours are provided to realize visitor-specific viewing experiences[10,11].

Overall, the research trend is shifting from technology-driven to more mature experience-driven paradigms. Still, challenges persist, including insufficient research on group social interaction, technical ethics and data privacy concerns, and high deployment costs. Future development will focus on more accurate understanding of complex emotions, social interaction design supporting group shared

experiences, and promote a new human - oriented museum era under the guarantee of ethical frameworks[12].

3. Theoretical Foundations of Affective Computing and Dynamic Interactive Design

3.1 Technical Core and Design Interfaces of Affective Computing

Affective Computing was first systematically elaborated by Professor Picard in 1997. Its core lies in equipping computers with capabilities to recognize, understand and even express human emotions[13]. In museum scenarios, non-intrusive emotion recognition technologies serve as critical feedback sources for design, mainly including:

Facial expression recognition: Computer vision analyzes facial muscle movements of visitors to identify basic emotions such as pleasure, surprise and confusion.

Speech emotion analysis: Extract features including tone and rhythm from interactive voice during guided tours to recognize emotional states.

Posture analysis: Somatosensory cameras analyze visitors' body postures, gestures and movement trajectories to infer their interest and engagement levels.

It should be highlighted that these technologies have achieved high modularization and commercialization (mature SDKs are available from open platforms such as Baidu AI and Megvii Face++). Designers do not need to delve into algorithmic details. Instead, they should treat them as an invocable "black box", and focus on how output data (e.g., pleasure score) can be adopted as design input parameters to drive changes in interactive content.

3.2 Artistic Principles of Dynamic Interaction Design

1.Narrative space theory: The museum space itself functions as a narrative field. Dynamic interaction breaks the constraints of linear narratives and enables branching and restructuring of storylines according to visitors' behaviors and emotions, generating non-linear and personalized narrative experiences[14].

2.Gestalt psychology: It advocates that human perception of objects operates holistically. In dynamic interaction, elements including light, color, sound effect and space shall be coordinated to form an emotional field that brings visitors holistic gestalt perception.

3.Artistic conception theory in traditional Chinese aesthetics: In Aesthetics Walk, Zong Baihua highlights that "the interplay of virtuality and reality" constitutes the core of artistic conception creation[15]. It provides supreme guidance for dynamic interaction design: the application of technology (the real) shall serve the construction of artistic conception (the virtual). For instance, visitors' gaze can trigger dynamic local effects on cultural relics. Such "blank-leaving" arouses visitors' cultural imagination, rather than force-feeding information.

To sum up, the theoretical foundation of this study is as follows: affective computing technologies act as "sensors" and "regulators", while artistic principles including narrative space theory, Gestalt psychology and artistic conception theory serve as "navigators" and aesthetic criteria. Together they form the theoretical and practical framework for dynamic interaction design.

4. Core Design Strategies for Dynamic Interaction in Museum Exhibitions

Based on the above theoretical integration, three core design strategies are proposed to systematically address the integration of affective computing and exhibition design.

4.1 Strategy 1: Dynamic Narrative Reconstruction Driven by Emotion Recognition

The core of this strategy is to treat emotions as real-time editing variables for narrative workflows, shifting the paradigm from "visitors follow preset storylines" to "storylines adapt to visitors".

First, build an "emotion-narrative node" mapping library. During exhibition planning, decompose core narratives into independent narrative nodes (e.g., discovery of cultural relics, craftsmanship decryption, historical background, cultural implication). Each node corresponds to specific emotional states.

When the system detects curious facial expressions from a visitor observing a bronze artifact, it can automatically trigger a 3D animation demonstrating its casting craftsmanship. If confusion is detected, textual descriptions will be dynamically simplified, and associated exhibits will be highlighted with graphic-text aids. In several experimental exhibitions at London's V&A Museum, attempts have been made to dynamically adjust hall lighting and music according to aggregated audience emotional data, which indirectly shapes narrative atmospheres[5].

4.2 Strategy 2: Adaptive Interaction Adjustment for Diverse User Groups

This strategy aims to resolve experience gaps among different visitor groups (e.g., the elderly, teenagers, professional researchers) arising from divergent cognitive habits and emotional needs.

A composite judgment mode combining "pre-set user profiles + real-time emotions" is adopted. When visitors enter the museum (via ticketing systems) or make active selections, basic interaction modes are matched. For elderly visitors, a "low-intensity, high-companionship" mode is enabled by default, featuring voice-based guided tours, enlarged fonts and slow-paced animations. For teenagers, a "high-intensity, gamified" mode with AR treasure hunts and puzzle-solving tasks is activated. Real-time emotional feedback is superimposed for fine-tuning on top of basic modes. For example, under the low-intensity mode for elderly visitors, if persistent low-interest signals are detected, voice clips of relevant collection stories may be pushed to recapture their attention. This strategy relies on lightweight integration between existing museum user management systems and emotion-recognition APIs, featuring low technical barriers and high practicability.

4.3 Strategy 3: Multi-sensory Collaborative Enhancement of Emotional Immersion

This strategy focuses on artistically designing cross-sensory channels to integrate visitors' visual, auditory and even tactile senses, so as to create and amplify specific emotional atmospheres.

Analyze the cultural attributes and emotional tones of exhibits (e.g., solemnity of bronze wares, elegance of porcelain, ethereality of traditional paintings and calligraphy), and formulate matched multi-sensory schemes.

Creation of solemn atmosphere: In bronze-artifact exhibition zones, adopt deep-toned and gradually-changing cool-colored light effects, and introduce low-frequency mild vibration feedback (via handheld

devices or modified exhibition stands). Both visual and somatosensory perceptions strengthen the solemnity and divinity of cultural relics.

Creation of elegant and serene atmosphere: In porcelain exhibition zones, apply soft warm-toned projection lighting, and play minimalist ambient sounds simulating natural white noise (e.g., wind rustling bamboo, drips of rain), jointly building an aesthetic space for quiet appreciation.

The creative philosophy of renowned art collective TeamLab centers on constructing immersive worlds. Their works perfectly merge digital technologies with visual-auditory interactions, fully demonstrating the huge potential of multi-sensory collaboration in evoking emotions[16].

5. Feasibility and Typical-Scenario Validation of the Strategies

5.1 Technical feasibility and integration path

The strategy proposed in this paper is not a castle in the air, and its implementation depends on the current popular technology ecology. Designers can use mature engines such as unity or unreal engine to build interactive content and logic, obtain real-time emotional data by calling the commercial emotion recognition API (as described above), and integrate it into the museum's existing digital navigation app or on-site interactive terminal. The whole technology path is clear, the division of modules is clear, and there is no need for disruptive innovation, which has a high degree of engineering feasibility.

5.2 Construction and logical deduction of typical interactive situations

For the application of visualization display strategy, we construct a typical interactive situation of "Dunhuang Flying mural".

The initial state is the static display of murals, and the environmental sound effect is the distant and ethereal Sanskrit sound. The interaction trigger is that the system camera (after anonymization, no individual biological information is stored) detects that the gaze behavior of audience a on the "flying" image exceeds the threshold value of 5 seconds, and the "pleasure" and "interest" indicators of its facial expression are significantly improved.

Apply strategy one and strategy three. First, dynamic narrative reconstruction. The system determines the narrative node that triggers the "flying cultural implication". Then design multi sensory collaborative immersion. The "flying" ribbon in the mural began to flow slowly according to the physical law, simulating the artistic conception of "Wu Dai Dangfeng"; At the same time, the background Sanskrit is blended with extremely subtle and soothing wind sound, which visually enhances the flow trajectory and color saturation of the streamer through the projection light effect.



Figure 1. Effect Diagram of Typical Interactive Scenario "Dunhuang Flying Apsaras Mural"

This interaction does not directly state the religious connotations or artistic value of Flying Apsaras. Instead, it triggers ribbon animations via the respectful act of gazing. Adopting the Chinese aesthetic principle of "interplay between virtuality and reality", it transforms the cultural imagery of "flying beauty" into perceptible emotional experiences, which effectively validates the aforementioned strategies.

5.3 Expected Performance and Evaluation Dimensions

The effectiveness of strategies can be verified through a mixed evaluation system in future empirical studies. Quantitative indicators include average dwelling time, emotional-curve fluctuation rates derived from expression recognition, and completion rates of interactive tasks. Qualitative indicators are obtained through subsequent semi - structured interviews, focusing on visitors' perceived sense of artistic conception and cultural resonance. For instance, statements such as "When the ribbons came alive, I could almost feel ancient people's longing for flight and romantic artistic conception" in interviews serve as direct evidence of successful strategy implementation.

6. Conclusions and Prospects

Targeting the lack of emotional dimensions in digital museum exhibitions, this study constructs a dynamic interaction design framework consisting of three strategies: dynamic narrative reconstruction, adaptive interaction adjustment, and multi-sensory collaborative immersion. Its primary innovation lies in systematically transforming affective computing from cutting-edge technology into operable design thinking and methodologies led by design science, emphasizing the navigational role of artistic theories in technology application.

This research has limitations. In-situ large-scale and long-term applications are still required to verify the universality and long-term effects of the proposed framework. Looking ahead, with advances in affective

computing (e.g., adoption of portable electroencephalogram devices), dynamic interaction will achieve higher precision and depth. Meanwhile, data privacy and design ethics must be considered prospectively. Future research shall strive to strike a balance between immersive-experience creation and visitor-privacy protection, formulate corresponding industrial design specifications, and guide the affective-oriented transformation of museums toward sound and responsible development.

Project

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