Postprint: Development Opportunities, Practical Challenges, and Mitigation Strategies for Embodied Intelligence Empowering Smart Library Construction

Authors: Wang Renjie, Yun Li

Date: 2025-07-09T14:47:01+00:00

Abstract

The rapid development of embodied intelligence provides new technological pathways for the digital transformation and service innovation of smart libraries. From the perspective of deep integration between embodied intelligence and smart libraries, this paper systematically explores its development opportunities, practical dilemmas, and mitigation strategies. First, from the four dimensions of technology integration, service upgrading, resource reconstruction, and experience innovation, it analyzes the development opportunities for embodied intelligence empowering smart library construction. Second, focusing on core issues such as technical bottlenecks, scenario limitations, management barriers, and acceptance obstacles, it reveals the technical adaptation dilemmas and ethical challenges faced in the process of embodied intelligence empowering smart library construction. Finally, it proposes targeted mitigation strategies, including constructing a hierarchical intelligent service architecture, building a virtual-real integrated service ecosystem network, improving institutional norms and governance frameworks, and promoting the construction of value consensus for human-machine collaboration, to advance the development of smart libraries in the era of embodied intelligence.

Full Text

Abstract

Embodied intelligence provides novel technical pathways for the digital transformation and service innovation of smart libraries. From the perspective of deep integration between embodied intelligence and smart libraries, this study systematically explores development opportunities, practical dilemmas, and resolution strategies. First, from four dimensions—technological integration, ser-

vice upgrading, resource restructuring, and experience innovation—we analyze the development opportunities of embodied intelligence empowering smart library construction. Second, we reveal the technological adaptation dilemmas and ethical challenges in this process, focusing on core issues such as technical bottlenecks, scenario limitations, management barriers, and acceptance obstacles. Finally, we propose systematic resolution strategies, including constructing a layered progressive intelligent service architecture, building a virtual-real integrated service ecosystem network, improving institutional norms and governance frameworks, and advancing value consensus building for human-machine collaboration, thereby promoting the development of smart libraries in the era of embodied intelligence.

Keywords: embodied intelligence; smart library; service paradigm transformation; ethics; human-machine collaboration

1. Development Opportunities of Embodied Intelligence Empowering Smart Library Construction

1.1 Technological Integration: Deep Coupling of Intelligent Technology and Library Services

Technological integration lies in constructing a co-evolution mechanism between intelligent technology and library business, coupling cognitive computing frameworks with physical service scenarios to enhance service capabilities. The embodied intelligence service model promotes knowledge services to deeply embed into users' cognitive processes, transforming from passive response to active intervention. At the resource dimension, intelligent service robots break through spatial constraints through semantic understanding modules, achieving context-aware interaction between collections and digital resources. This technology integration not only enhances service effectiveness through intelligent technology but also feeds back algorithm evolution through scenarios, establishing a two-way value channel. For instance, interactive data from library immersive learning spaces can optimize emotional computing model parameters, improving the system's recognition accuracy of cognitive fatigue.

1.2 Service Upgrading: Transformation from Standardization to Personalization

The core of service paradigm transformation lies in breaking through the efficiency limitations of standardized services to build a personalized service system oriented toward user cognition. Traditional library cataloging systems are constructed based on document features, whereas the user profiling system supported by embodied intelligence can capture individual cognitive styles, interest preferences, and learning patterns, transforming service supply from resource matching to cognitive rhythm synchronization. In library space services, adaptive lighting and acoustic field control dynamically optimize the cognitive support characteristics of reading environments based on users' brainwave data and

heart rate variability indices, creating personalized learning ecosystems. This service upgrade fundamentally represents a shift in service logic from information transmission to knowledge construction.

1.3 Resource Restructuring: Efficiency Optimization of Full-Process Knowledge Management

Resource restructuring aims to break the linear logic of traditional literature management and establish a full lifecycle management system based on cognitive value mining. Embodied intelligence systems embed into resource utilization contact points, achieving full-process perception and intelligent intervention of knowledge flow through digital twin technology. In resource acquisition, intelligent procurement models can construct demand-driven dynamic resource building mechanisms by combining user behavior prediction and discipline hotspot evolution trends. In resource utilization, augmented reality technology superimposes digital resources onto physical collections, achieving multi-dimensional and stereoscopic knowledge presentation. The resource evaluation system no longer relies solely on usage frequency indicators but quantifies the cognitive transformation efficiency of resources through eye tracking and interaction behavior analysis, providing cognitive scientific basis for resource iteration.

1.4 Experience Innovation: Embodied Interaction Driving User Cognitive Efficiency Enhancement

Experience innovation requires activating users' cognitive subjectivity through embodied interaction mechanisms to build an immersive knowledge construction environment. Intelligent navigation systems can dynamically adjust guidance information based on users' knowledge exploration paths, making each user's cognitive interaction process become feedback data for optimizing the resource system. This two-way empowerment mechanism not only grants autonomous evolution capability to library resource systems but also forms a spiral ascending technology iteration mechanism. In ancient book digitalization special collection areas, users can obtain collation information through gesture operations, while tactile feedback devices can simulate the texture of ancient paper. This multisensory collaborative interaction design not only enhances the immersion of cultural experience but also deepens users' understanding of document content through embodied cognitive mechanisms.

2. Practical Dilemmas in Embodied Intelligence Empowering Smart Library Construction

2.1 Technical Bottlenecks: Insufficient Environmental Adaptability and Computing Power Constraints

Technical bottlenecks mainly concentrate on insufficient environmental adaptability of intelligent agents and computing power constraints, which are reflected in both physical and cognitive dimensions. At the physical level, dy-

namic changes in bookshelf spacing and diverse document carrier forms make it difficult for SLAM systems to maintain centimeter-level positioning accuracy, easily causing path planning failure. At the cognitive level, concurrent tasks such as 3D environment reconstruction and natural language understanding expose the shortcomings of multi-modal data fusion analysis algorithms, often resulting in gesture misjudgment or incorrect document coordinate positioning. Computing power constraints force compromises between decision depth and response speed, with navigation robots experiencing multi-second delays when encountering unexpected obstacles. The computing resource constraints of edge computing devices create sharp contradictions between performance and energy consumption, making it difficult to meet real-time optimization needs.

2.2 Scenario Limitations: Homogenized Application Patterns and Blurred Value Boundaries

Smart libraries face the dual dilemma of homogenized application patterns and value cognitive bias in embodied intelligence applications, causing technological innovation to fall into inefficient repetitive construction and service function alienation. Many libraries configure similar functions such as navigation and virtual assistants in large numbers, which, while improving basic business efficiency, alienate technological utility from cost. A more severe crisis lies in the structural mismatch between technological availability and scenario necessity, which not only weakens the social function of libraries as knowledge intermediaries but also squeezes innovation space in segmented fields. In special group services and cultural heritage digitalization fields with differentiated needs, there exists a conflict between scenario heterogeneity and technological isomorphism.

2.3 Management Barriers: Coordination Dilemmas of Data Ethics and Operational Mechanisms

Data ethics and operational mechanism coordination dilemmas constitute multiple management barriers in smart library construction. At the data ethics level, multi-modal data streams generated by embodied intelligence trigger new governance crises. The dynamic collection of user location trajectories, physiological characteristics, and other sensitive data does not match the current generalized authorization model, causing informed consent mechanisms to become formalistic. Data control rights actually shift to technology providers, while algorithm black boxes further cause decision-making untraceability. At the operational mechanism level, fragmented management conflicts with integrated intelligent services, and the independent workflow of departments such as resource acquisition weakens the ability to respond to user needs in a coordinated manner. The sustainability of long-term operation models is insufficient, relying on government special appropriations that cannot meet hardware loss rates exceeding expectations.

2.4 Acceptance Obstacles: User Cognitive Inertia and Technological Trust Gap

The popularization of smart libraries faces dual obstacles of user cognitive inertia and technological trust gap. In terms of cognitive inertia, users have formed significant path dependence on manual services over decades, trusting librarians' experience more than algorithmic recommendations. This inertia presents obvious conflicts in spatial perception dimensions. The technological trust crisis stems from the accumulation of negative experiences in human-computer interaction. Issues such as inaccurate intelligent recommendations, voice assistant dialect recognition errors, and information inaccuracy of recommendation systems not only weaken trust in individual systems but may evolve into group-level technological skepticism. Deeper contradictions manifest in the dissolution of the sense of ritual in knowledge acquisition by technological logic, with some users interpreting convenience as loss of cultural depth.

3. Resolution Strategies for Embodied Intelligence Empowering Smart Library Construction

3.1 Technical Breakthrough: Constructing a Layered Progressive Intelligent Service Architecture

Constructing a layered progressive intelligent service architecture is the core pathway to break through environmental adaptability and computing power constraints. At the infrastructure layer, establish adaptive edge computing architecture to alleviate computing power and energy consumption conflicts. Deploy LiDAR and pressure sensors in bookshelf areas to monitor crowd density, combined with dynamic calibration technology to maintain positioning accuracy. At the data platform layer, build multi-modal fusion mechanisms, using multi-dimensional data analysis technology to integrate borrowing records, voice logs, and user behavior data, developing dynamic association models. Employ lightweight model compression technology to support parallel computing of 3D environment reconstruction and natural language understanding. At the application interface layer, strengthen multi-agent collaboration, optimize robot collaborative path planning through standardized communication protocols, and embed conflict detection algorithms to prevent trajectory overlap.

3.2 Scenario Reconstruction: Building a Virtual-Real Integrated Service Ecosystem Network

Building a virtual-real integrated service ecosystem network requires breaking through the physical boundaries of traditional service scenarios and reshaping library spatial attributes and service models through digital twin and embodied interaction technologies. At the spatial reconstruction dimension, create mixed reality service interfaces using spatial navigation and holographic projection technology, enabling users to obtain virtual bookshelf documents through gesture interaction. At the service extension dimension, develop embodied intel-

ligent agent systems deeply integrated with situational awareness, constructing continuous service chains in users' daily scenarios. At the ecological collaboration dimension, build heterogeneous technical frameworks between libraries and urban cultural facilities, using blockchain and smart contract technology to achieve effective scheduling of multi-institution resources. In local chronicle literature search scenarios, intelligently associate archive manuscript images with museum 3D models to promote cultural memory inheritance practices.

3.3 Mechanism Innovation: Improving Institutional Norms and Governance Frameworks

Institutional norm innovation should focus on resolving structural contradictions between technological empowerment and risk control, building a collaborative governance system compatible with embodied intelligence characteristics. Establish an intelligent service graded supervision system, reconstructing risk prevention frameworks based on data sensitivity and algorithmic impact scope. For high-risk systems such as behavior prediction, establish dual traceability pathways for both technical logs and accountability lists. Build a comprehensive data governance framework, formulating full lifecycle management rules from data generation to destruction, and establish inter-library federated learning models. Establish a resilience operation mechanism, simulating hardware loss predictions through digital twin technology, and constructing sustainable operation cost models.

3.4 Cognitive Reshaping: Advancing Value Consensus Building for Human-Machine Collaboration

Advancing value consensus building for human-machine collaboration requires breaking through traditional cognitions of technological instrumentalism and cultivating new service relationships from the perspective of subject relationship reconstruction. Conduct intelligent literacy cultivation, reshaping librarians' capability structures through tiered training systems. For management, hold technology strategy workshops to help them understand the technical boundaries and ethical challenges of embodied intelligence. For service librarians, develop virtual reality scenario drills to cultivate core capabilities such as data interpretation and anomaly judgment. Build a multi-party collaborative design platform, transforming technology development into cultural adaptation experiments. Introduce ritual sense enhancement modules in service interface design, allowing users to vote on queuing rules and converting voting results into algorithmic weights, thereby rebuilding the sense of ritual in knowledge acquisition.

4. Conclusion

Embodied intelligence integrates perception, interaction, and cognitive decision-making, deeply 融入 library intelligent service scenarios through multi-modal environmental perception and adaptive learning capabilities. Its unique con-

textual understanding and dynamic execution mechanisms provide technical support for library spatial reconstruction and service upgrading, demonstrating unique advantages in optimizing user experience and enhancing service effectiveness. This study systematically analyzes the development opportunities of embodied intelligence empowering smart library construction, and proposes constructing a layered progressive intelligent service architecture, building a virtual-real integrated service ecosystem network, improving institutional norms and governance frameworks, and advancing value consensus for human-machine collaboration to address practical dilemmas. It should be noted that embodied intelligence, as a technical carrier for smart library intelligent transformation, requires transcending the application limitations of instrumental rationality to achieve organic integration with knowledge service ecosystems. Future research should focus on exploring technical paths for intelligent recommendation systems to adapt to different groups' cognitive characteristics, constructing algorithmic transparency accountability mechanisms, and promoting bidirectional mutual feedback between library science theoretical innovation and intelligent technology evolution.

Note: Figure translations are in progress. See original paper for figures.