Intelligent Diversified Smart Elderly System from the Perspective of AI+ and IoT

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Abstract: Driven by the accelerating trend of population aging and the iterative advancement of digital technology, traditional elderly care models face bottlenecks such as insufficient service precision and lagging response times. This paper proposes an intelligent diversified smart elderly system deeply integrated with AI and IoT. By constructing a full-chain technical system of "Perception-Transmission-Decision-Application," it integrates multimodal perception, intelligent decision-making, and scenario-based service functions to provide diversified support for health management, safety protection, daily life services, and emotional companionship. The system is characterized by passive sensing and active intervention, breaking through the limitations of traditional "passive care" and building a linked ecosystem involving "Family-Community-Institution-Medical care." The research elaborates on the system architecture design, core technology integration paths, and application logic, providing engineering references for the implementation of smart elderly care technologies.

Keywords: Smart Elderly System; Multimodal Perception; Active Intervention

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1 Research Background and Significance

1.1 Research Background

Against the backdrop of an increasingly severe global aging trend, the demand for elderly care services is gradually transforming and upgrading from basic survival security to higher-level quality and personalization. Traditional elderly care models, heavily reliant on labor-intensive services, struggle to cope with the dual challenges of scale expansion and demand diversification. To address this, the General Office of the State Council issued the "Opinions on Developing the Silver Economy to Enhance the Well-being of the Elderly," explicitly proposing the strategic goal of creating new formats for smart health and elderly care, emphasizing the need to reconstruct the entire chain of elderly care services through technological innovation. Guided by this policy, the comprehensive perception capability of the Internet of Things (IoT) and the intelligent decision-making advantages of Artificial Intelligence (AI) form a natural complementary relationship, providing powerful technical support to break through current bottlenecks in elderly care services, thereby promoting the shift from traditional "passive care" to a more proactive "preventive care" model, ushering in the era of Elderly Care 4.0.

1.2 Research Status

Currently, most existing smart elderly care systems focus on single functional scenarios, such as health monitoring or safety alerts, leading to issues like data silos and fragmented services. Although some systems attempt to integrate AI and IoT technologies, the design of the perception layer still lacks considerations for unobtrusiveness, the decision-making layer fails to achieve deep integration of multimodal data, and the application layer overlooks the individual differences in digital adaptability among the elderly. Facing these shortcomings, current research urgently needs to construct a diversified system architecture that balances technical integration, covers diverse scenarios, and adapts to different user needs, aiming to achieve a value leap from mere "technology stacking" to a greater emphasis on "humanistic care."

1.3 Research Content and Significance

From an engineering practice perspective, this paper designs and elaborates on the technical architecture and implementation path of the intelligent diversified smart elderly system, focusing on overcoming key technical challenges such as multi-scenario perception coordination, cross-domain intelligent data analysis, and personalized service delivery. By integrating non-contact monitoring technology, affective computing, and intelligent linkage technology, the system aims to provide comprehensive smart service support covering the entire life cycle and all scenarios for the elderly. Its research significance lies not only in providing a replicable technical framework for the engineering implementation of smart elderly care systems but also in promoting the deep integration of the silver economy and digital technology, contributing new solutions for improving the quality of life and well-being of the elderly.

2 Architecture Design of the Intelligent Diversified Smart Elderly System

2.1 Overall Architecture Design

The system adopts a "Five-Layer, Three-Domain" three-dimensional architecture. Based on the IoT perception network, centered on the AI algorithm engine, and outputting diversified services, it constructs a closed-loop system of "Monitoring-Analysis-Intervention-Optimization." The five-layer architecture includes the Perception Layer, Transmission Layer, Platform Layer, Application Layer, and Support Layer. The three domains cover Home-based Care, Community Service, and Institutional Care scenarios. A data platform enables cross-scenario resource coordination and service linkage, breaking down the spatial barriers and data isolation of traditional elderly care services.

2.2 Core Layer Function Design

2.2.1 Perception Layer: Multimodal Unobtrusive Data Collection

The perception layer adopts an "Active + Passive" fused perception scheme to build a full-scenario data collection network. Active perception devices include terminals like wearable bracelets and smart pillboxes, enabling active monitoring of heart rate, medication behavior, etc. Passive perception uses technologies such as video imaging and wireless signal analysis to extract cardiovascular parameters, limb movements, and emotional states without physical contact, solving the issues of discomfort from traditional sensor wear and privacy leakage. Device selection follows medical-grade accuracy standards, supports offline caching and breakpoint resume transmission, adapting to the complexity of elderly usage scenarios.

2.2.2 Transmission Layer: Multi-Protocol Secure Data Flow

The transmission layer adopts a "Hybrid Networking + Hierarchical Transmission" strategy to adapt to the communication needs of different scenarios. Indoor environments use a hybrid Bluetooth and LoRa network to reduce the impact of wall obstructions on signals; outdoor scenarios rely on the NB-IoT wide-coverage network to ensure the continuity of positioning data; emergency alert information is prioritized for transmission via 5G private networks to achieve millisecond-level response. Data transmission is encrypted using national cryptographic algorithms, with sensitive information additionally protected by dynamic token verification. Local data cleaning is performed through edge computing gateways to reduce redundant transmission and privacy exposure risks.

2.2.3 Platform Layer: Intelligent Data Processing Hub

The platform layer constructs a dual-core processing architecture of "Data Platform + AI Engine." The data platform achieves standardized integration of multi-source data, covering dimensions such as health records, device status, and service records, supporting cross-department data sharing and dynamic updates. The AI engine integrates machine learning, knowledge graphs, and affective computing technologies. It optimizes prediction models under the premise of privacy protection through federated learning, enabling functions such as health risk assessment, abnormal behavior recognition, and personalized service recommendation. The platform supports low-code configuration to quickly respond to the dynamic changes in elderly care service demands.

2.2.4 Application Layer: Diversified Scenario-based Service Output

The application layer designs exclusive service modules for different user groups, forming a diversified service matrix. Terminals for the elderly use voice interaction and large-screen display designs, providing convenient functions such as medication reminders and activity appointments. The family member APP enables remote care functions like health status queries and service progress tracking. The management end displays operational indicators through a visual dashboard, supporting service resource scheduling and quality monitoring. The medical staff end integrates functions like video consultations and health education, achieving seamless connection of medical and care services. Modules are linked through API interfaces to ensure the timeliness and accuracy of service responses.

2.2.5 Support Layer: Full-Process Standardized Security Support

The support layer constructs a system security system from three dimensions: technology, management, and regulations. Technically, measures such as data desensitization and hierarchical access control are adopted to protect the privacy information of the elderly. Management-wise, mechanisms for regular equipment inspection, data backup, and emergency response are established to ensure stable system operation. Regulatory compliance follows medical data compliance standards, achieving compliant data exchange with third-party medical platforms. Simultaneously, aging-adapted transformation standards regulate terminal design to enhance system usability.

3 Core Technology Integration Paths of the System

3.1 Synergistic Mechanism of IoT Perception and AI Algorithms

The system achieves deep integration of perception and algorithms through "Edge Computing + Cloud Collaboration." Edge nodes are responsible for real-time data preprocessing and simple decision-making, such as preliminary identification of fall events. The cloud AI engine performs complex data mining, such as disease risk prediction based on long-term health data. This collaborative model reduces transmission bandwidth pressure, improves decision-making response speed, and optimizes perception parameters through device self-learning algorithms, enhancing the accuracy and adaptability of data collection.

3.2 Multimodal Data Fusion and Intelligent Decision-Making Technology

Addressing the complexity of state perception for the elderly, the system employs multimodal data fusion algorithms to integrate information from dimensions such as physiological indicators, behavioral characteristics, and environmental parameters. Using theories like the Affective State Transition Tensor Network, it achieves cross-modal emotion recognition from facial expressions, voice tones, and body movements. A health risk assessment model is built based on deep learning, combined with a Traditional Chinese Medicine knowledge base of "Food as Medicine" to generate personalized intervention plans. The decision-making process adopts a dual-driven mode of "Rule-based Reasoning + Model Prediction" to ensure the scientific nature and practicality of service recommendations.

3.3 Cross-Scenario Service Linkage and Intelligent Intervention Technology

The system achieves full-chain intervention through "Horizontal Scenario Coordination + Vertical Service Linkage." Horizontally, home devices are interconnected with community station and nursing institution systems, for example, home fall alarms are automatically synchronized to community security terminals. Vertically, it integrates health monitoring, emergency rescue, and subsequent rehabilitation services to form a closed-loop intervention system. The intervention method adopts a "Graded Response" mechanism: mild abnormalities trigger voice reminders, while severe situations automatically link medical staff and family members. Simultaneously, environmental linkage control is achieved through IoT devices, such as automatically closing the gas valve and activating ventilation upon gas leakage detection.

4 System Application Scenarios and Practical Logic

4.1 Home-based Care Scenario: Personalized Autonomous Care

The home scenario focuses on "Unobtrusive Monitoring + Active Services," embedding smart devices through aging-adapted home modifications. Non-contact cardiovascular monitoring systems are integrated into household TVs or monitoring devices, analyzing health status in real-time and pushing dietary suggestions. Smart pillboxes provide voice medication reminders and notify family members and caregivers if not opened on time. Environmental sensors monitor parameters like temperature, humidity, and gas concentration, automatically adjusting home appliances when anomalies are detected. The system supports voice interaction and simplified operations, lowering the digital usage barrier for the elderly.

4.2 Community Service Scenario: Grid-based Collaborative Support

The community scenario builds a "15-Minute Elderly Service Circle," integrating diverse services through smart service stations. Stations deploy health monitoring terminals, providing self-service physiological index detection and report interpretation. A service platform enables the closed loop of online ordering, dispatch, and evaluation, covering life services like meal assistance and housekeeping. Security deployment is optimized using passage heat maps, combined with electronic fences to prevent the elderly from getting lost. The system links with community hospitals to achieve interoperability between health data and medical information, improving the efficiency of primary medical services.

4.3 Institutional Care Scenario: Refined Operational Management

The institutional scenario achieves standardization and efficiency of care services through a digital system. A management dashboard displays real-time indicators such as the structure of resident elderly, equipment status, and service orders, supporting drill-down analysis and resource optimization. Medical staff monitors the health status of high-risk elderly via large screens, automatically generating nursing task reminders. By analyzing activity participation rates, course schedules are dynamically optimized, and personalized meals are recommended based on nutritional preferences and health data. The system reduces the labor costs of institutions while improving service accuracy and satisfaction.

5 System Implementation Challenges and Development Prospects

5.1 Existing Implementation Challenges

System implementation faces three core challenges: First, the digital aging-adaptation gap, where some elderly have low acceptance of smart devices, requiring further optimization of interaction design and skills training. Second, data security and privacy protection pressures, where information leakage risks exist during multi-source data sharing, necessitating improved technical protection and regulatory constraints. Third, cross-departmental collaboration barriers, where data standards among civil affairs, healthcare, and other systems are inconsistent, affecting the efficiency of service linkage.

5.2 Future Development Directions

Addressing the above challenges, the system will iterate and upgrade in three directions: Technologically, introducing embodied AI and virtual reality technologies to transform emotional companion robots from tools into "emotional partners," bridging the intergenerational digital gap through virtual-real integration. Application-wise, building a "Silver Economy Ecosystem Platform" to integrate resources for product R&D, service supply, and operational management, promoting the industrialization of elderly care services. Standardization-wise, participating in the formulation of data sharing and device interconnection standards for smart elderly care to promote cross-domain collaboration and technology implementation.

6 Conclusion

The AI+IoT intelligent diversified smart elderly system designed in this paper achieves deep integration of multi-scenario perception, multi-dimensional analysis, and diversified services through the "Five-Layer, Three-Domain" architecture, breaking through the passive and fragmented limitations of traditional elderly care services. Based on unobtrusive perception, centered on intelligent decision-making, and utilizing collaborative intervention as the means, the system constructs a full-scenario elderly care service system covering home, community, and institution. Practice shows that the system amplifies the value of humanistic care through technological empowerment, enhancing both the efficiency and precision of elderly care services while respecting the autonomy and privacy needs of the elderly. In the future, through technological innovation, standard construction, and ecological collaboration, it is necessary to further promote the large-scale implementation and sustainable development of the system, providing strong support for the development of the silver economy.

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