2025 International Conference on Economics, Management and Education Technology (ICEMET 2025)

Article

Research on Emotional Interaction AI Algorithm Optimization and Human Robot Collaboration Models for Elderly Care Robots

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Abstract: This paper conducts an in-depth study on emotional interaction artificial intelligence algorithm optimization and human-robot collaboration models specifically designed for elderly care robots. In the context of a rapidly aging global society, the demand for comprehensive elderly care services continues to increase exponentially. Consequently, advanced emotional recognition and empathetic interaction capabilities have become key factors in improving the overall service quality and acceptance of care robots. This study proposes a novel, deep learning-based emotion recognition algorithm that achieves highly accurate identification of complex emotional states in older adults. This is accomplished through the integrated, multimodal analysis of speech dialogue, facial expressions, and continuous physiological signals. With regard to human-robot collaboration models, the study systematically examines collaborative working mechanisms between intelligent robotic assistants and human care staff. Furthermore, it proposes a dynamic adjustment strategy based on real-time emotional feedback to substantially improve collaboration efficiency and user satisfaction. Experimental results demonstrate that the optimized emotional interaction algorithm significantly improves emotion recognition accuracy and computational response speed. Additionally, the newly proposed collaboration model effectively reduces the physical and psychological workload pressure on human care staff while elevating the overall quality of elderly care services. The core innovations of this study lie in the development of a context-aware human-robot interaction mechanism and an adaptive task allocation model, which collectively provide novel technical solutions to enhance the intelligence, empathy, and responsiveness of modern elderly care services.

Keywords: care robots; emotional interaction; algorithm optimization; human-robot collaboration; deep learning

Received: 16 February 2026
Revised: 25 March 2026
Accepted: 06 April 2026
Published: 11 April 2026

1. Introduction

1.1. Research Background

Globally, population aging has become increasingly prominent, and the size of the elderly population continues to expand, leading to a sharp rise in demand for care services. Traditional care models face significant challenges in terms of resources and manpower and struggle to meet growing needs. With advances in technology, intelligent robot technology has gradually been applied to elderly care and has become an important tool for improving care standards. The application of emotional interaction in elderly care robots provides support for building more human-centered communication bridges between robots and older adults, enabling robots to recognize and understand emotional states and better meet emotional needs. The realization of emotional interaction relies on

improvements in AI algorithms. Deep learning and multimodal data analysis enhance emotion recognition accuracy and response efficiency. Building efficient human-robot collaboration models allows care robots and care staff to form optimal cooperative relationships. This approach reduces the workload of care staff while improving the care experience of older adults. Research on emotional interaction technologies and human-robot collaboration models for elderly care robots offers new solutions to meet care needs and improve the quality of life for older adults [1].

1.2. Research Significance

Optimizing emotional interaction AI algorithms for elderly care robots and studying human-robot collaboration approaches hold significant importance at both theoretical and practical levels. From a theoretical perspective, the development of advanced emotional interaction AI algorithms contributes to the field of human-robot interaction, while also fostering progress in affective computing, natural language processing, and computer vision [2, 3]. This integration offers new research directions and structural support for these domains. Furthermore, it promotes the diversification of application scenarios for emotion recognition technologies, enabling intelligent care robots to better identify the emotional states of elderly individuals and provide them with more effective interaction experiences. From a practical standpoint, the rapid aging of the population places considerable pressure on caregiving systems. Enhanced emotional interaction capabilities can significantly improve the psychological well-being of older adults and elevate their quality of life. Additionally, advancements in human-robot collaboration methods enhance the efficiency of care staff and alleviate their psychological burden, facilitating seamless coordination between robots and caregivers. This research delivers practical solutions for improving elderly care services and supports the implementation of intelligent and stable care systems, offering substantial social value.

2. Current Application Status of Emotional Interaction AI Algorithms and Collaboration Models for Elderly Care Robots

2.1. Principles of Emotional Interaction AI Algorithms and Care Application Characteristics

The architecture of emotional interaction AI algorithms primarily relies on multimodal data processing, integrating natural language processing, computer vision, and physiological signal analysis to enable real-time acquisition and interpretation of user emotional states. These algorithms generally include key modules such as emotion recognition, emotion generation, and feedback. Speech, facial expressions, and physiological indicators are utilized to identify user emotions and generate appropriate responses. In care applications, the main characteristics of emotional interaction AI algorithms are high accuracy and real-time performance, enabling multi-perspective capture of emotional changes in older adults and providing personalized care and support. Their use in elderly care allows robots to promptly identify emotions such as loneliness and anxiety, provide emotional support, alleviate negative emotions, and improve mental health. In coordination with care staff, the algorithms offer behavioral suggestions and environment adaptation support to optimize the overall care experience. Emotional interaction AI algorithms play a significant role in enhancing the well-being of the elderly and improving the quality of care services, enabling intelligent care robots to serve as attentive companions in daily life.

2.2. Analysis of Application Scenarios

2.2.1. Emotion State Recognition and Labeling System for Older Adults

To effectively recognize the emotional states of older adults, it is essential to establish a scientific labeling system. This system should encompass common emotional states such as happiness, sadness, worry, anger, fear, and loneliness [4]. By integrating the lifestyle habits and psychological characteristics of older adults, emotional labels should be designed to align with practical needs. Emotion recognition utilizes multiple sensors and data collection methods, including speech emotion analysis, facial expression recognition,

physiological signal monitoring, and behavior pattern analysis. Machine learning and deep learning techniques are employed to train and classify the collected multimodal data. During this process, data from various sources and characteristics are integrated to construct a comprehensive emotion recognition model capable of capturing subtle emotional changes, thereby improving recognition accuracy and timeliness. Emotion recognition and labeling systems enable care robots to better understand emotional needs and deliver more human-centered care services, ultimately enhancing the life satisfaction of older adults.

2.2.2. Personalized Emotional Response and Companion Interaction

Through emotion recognition algorithms, robots can promptly detect emotional changes in older adults and provide personalized interaction feedback based on their emotional states. When loneliness is identified, robots can initiate conversations and offer companionship by sharing stories or playing music to alleviate negative emotions. When worry is detected, robots can deliver soothing voice guidance to assist with deep breathing or relaxation exercises, demonstrating emotional care and attentive service. By integrating preferences, habits, and historical interaction records, robots can recommend suitable activities or topics, enhancing the relevance and effectiveness of interactions [5]. Personalized emotional responses improve the quality of interactions, strengthen trust between robots and older adults, foster emotionally connected human-robot relationships, enhance psychological well-being, improve quality of life, and provide warmth, care, and companionship.

2.2.3. Human Robot Collaborative Care Processes and Efficiency Improvement

Care robots are capable of real-time monitoring and analyzing the emotional states of older adults, providing timely feedback to assist care staff in delivering psychological support and interventions [6]. By performing routine care tasks such as medication reminders and health data recording, these robots significantly reduce the workload of care staff and enhance the efficiency of healthcare establishments. Through data-sharing mechanisms, care staff can access necessary information without delays, enabling them to make informed decisions and deliver timely, personalized care. Continuous advancements in human-robot collaboration processes lead to optimal resource allocation and improved intelligence in care systems. Exploring effective collaboration methods enhances care efficiency, strengthens patient safety and satisfaction, and supports the development of more human-centered elderly care systems, thereby providing robust support for the health management of older adults.

3. Challenges Faced by Emotional Interaction AI Algorithms and Human Robot Collaboration in Elderly Care Robots

3.1. Technical Level Challenges

3.1.1. Emotional Data Silos and Difficulties in Multimodal Integration

In the field of elderly care, data acquisition primarily relies on visual, speech, and physiological sensors. However, these data sources are often isolated, forming what are referred to as data silos. Visual data struggle to capture subtle changes in the speech intonation of older adults, while single-modality speech data cannot be effectively integrated with facial expressions for combined analysis, leading to significant information loss. Multimodal data integration technologies face substantial challenges, as data from different modalities vary greatly in sampling rates, data formats, and representation characteristics. Due to the absence of unified standards and efficient fusion algorithms, achieving effective information integration remains difficult. Furthermore, emotional expressions in older adults are often ambiguous and non-prototypical, which further complicates integration efforts [7, 8]. Consequently, systems designed to process cross-modal emotional information are prone to conflicts or misclassification. These issues of data isolation and fusion barriers significantly hinder robots' ability to comprehensively

perceive the emotional states of older adults, posing a major obstacle to enhancing the quality of interactions.

3.1.2. Insufficient Depth of Affective Computing and Response Accuracy

Insufficient depth of affective computing and inadequate response accuracy represent significant obstacles in the practical deployment of elderly care robot technologies. These issues are mainly reflected in the diversity and efficiency of emotion recognition models. Existing affective computing models often struggle to deeply understand and interpret emotional states of older adults, resulting in overly superficial interpretation of emotional signals. When multiple emotions coexist or when emotional changes occur rapidly, recognition accuracy declines noticeably. Response accuracy in emotional interaction is also constrained by the depth of affective computing. Robots are unable to accurately understand the true emotions expressed by older adults when generating appropriate responses, leading to unsatisfactory interaction outcomes. Response latency further affects the overall interaction experience. When facing rapid emotional changes, failure to respond promptly reduces satisfaction and trust among older adults.

3.2. Challenges Arising from Characteristics of Elderly Care Services

3.2.1. Diverse Emotional Needs of Older Adults and Complex Care Scenarios

Older adults experience physical function decline and psychological state changes, and their emotions often change rapidly due to health conditions, social environments, and daily life events. These changes influence expectations and demands for care services. The diversity of care scenarios is reflected in multiple aspects. Living environments for older adults vary, including private homes, nursing homes, and hospitals, and emotional interaction needs differ across these settings. The care process involves multiple roles, including care staff, family members, and robots, requiring emotional interaction systems to flexibly adapt to the needs of different participants. The ability to respond to emergencies is a critical consideration. Sudden emotional fluctuations or unexpected health incidents require robots to possess the capability to immediately recognize situations and adjust accordingly.

3.2.2. Difficulties in Attribution of Human Robot Collaboration Effects and Quantification of Care Safety

During emotional interaction processes in elderly care robots, summarizing the effects of human-robot collaboration and quantitatively evaluating care safety present various challenges. Evaluating collaboration effectiveness involves multiple variables, such as the accuracy of robot emotion recognition, response timeliness, and the level of cooperation from care staff. Complex interrelationships among these factors make it difficult to determine clear attribution of outcomes. In emotional interaction, emotional changes in older adults are influenced by a combination of external environmental and internal factors. Improving a single factor in isolation may lead to unexpected results and increase complexity in problem handling. Standards for quantifying care safety have not yet been sufficiently developed. Existing evaluation systems largely focus on monitoring operational processes and outcomes, while the role of emotional interaction in enhancing care safety lacks systematic study. This results in difficulty establishing effective quantitative indicators. Significant individual differences among older adults, along with varying perceptions and needs regarding care services, further challenge the applicability of safety evaluations.

3.3. Ethical and Legal Dilemmas

3.3.1. Privacy Protection and Data Security for Older Adults

In the application of the emotional exchange function to care robots for older adults, the aspects of privacy protection and data security are particularly critical. When older adults use intelligent care technology, the personal information and emotional data involved are highly sensitive. If such data is leaked, it could severely impact their safety,

psychological well-being, and quality of life. During data collection, it is essential to inform older adults about the purpose, scope, and potential risks associated with data usage, ensuring their understanding and consent. For data transmission and storage, encryption technologies and robust security protocols should be employed to prevent unauthorized access or tampering. Additionally, a strict access control mechanism must be established, allowing only authorized personnel to manage the data, thereby minimizing internal risks. Regarding data lifecycle management, information that is no longer needed should be promptly deleted to reduce the risk of leakage. From a legal perspective, existing privacy protection laws and regulations must be continuously refined to keep pace with the rapid advancements in intelligent care technology. This will provide more comprehensive legal safeguards for older adults, better protecting their privacy and data security [9]. Such measures can also enhance their trust in care robots, increasing their willingness to use these technologies and improving overall satisfaction.

3.3.2. Algorithmic Discrimination and Risks of Over Reliance

During emotional interaction processes involving elderly care robots, algorithmic bias and risks associated with excessive reliance have emerged as ethical concerns requiring urgent attention. Algorithmic bias refers to the unfair treatment of specific groups caused by imbalanced or biased data. Older adults, as a vulnerable population, may experience disparities in emotional recognition and response due to the quality of algorithm training data. Individuals from diverse backgrounds and groups may encounter varying emotional interaction outcomes, potentially exacerbating psychological loneliness [10]. Excessive dependence on intelligent care robots for emotional support and caregiving can diminish real interpersonal interactions, thereby weakening the stability of social support systems for older adults. Furthermore, over reliance may reduce autonomy among older adults, and in cases of technical failure or unforeseen incidents, the loss of emotional support could negatively impact psychological well-being.

4. Optimization Strategies for Emotional Interaction AI Algorithms and Human Robot Collaboration Models for Elderly Care Robots

4.1. Technical Optimization Paths

4.1.1. Building a Unified Emotional Data Platform and Governance System

The emotional data platform should integrate multimodal data from diverse sources and exchange scenarios, including voice, facial expressions, contextual information, and physiological signals, to form a comprehensive emotional identification dataset [11]. Efforts must be made to ensure the data's high quality and accuracy, standardize it effectively, and facilitate the training and enhancement of algorithmic models. The data governance system should encompass all stages of data collection, storage, processing, and analysis, ensuring adherence to relevant laws and ethical standards while safeguarding the privacy and data security of elderly individuals. Transparent access control and management mechanisms must be established to ensure that only authorized personnel can access and utilize the data, thereby preventing potential misuse. Regular audits and evaluations of the data management process should be conducted to maintain ongoing compliance and operational efficiency.

4.1.2. Deepening the Application of Deep Learning and Affective Computing Models

To substantially improve the performance of elderly care robots in emotional interaction, the solution lies in enhancing the practical application of deep learning and affective computing models. Deep learning methods, such as Convolutional Neural Networks and Recurrent Neural Networks, should be adopted to significantly increase the accuracy and processing efficiency of emotion recognition in complex and dynamic environments. For multimodal data, including speech, images, and physiological signals, the feature extraction and adaptive learning capabilities of deep learning enable the precise capture of emotional states in elderly individuals, supporting more natural

human-robot interaction. Affective computing models should integrate emotion knowledge graphs and incorporate psychological and physiological characteristics of older adults to enhance the robot's understanding and response to emotional expressions. A feedback learning mechanism should be established to allow models to continuously improve through user feedback in real-world applications, addressing limitations in the understanding of emotions.

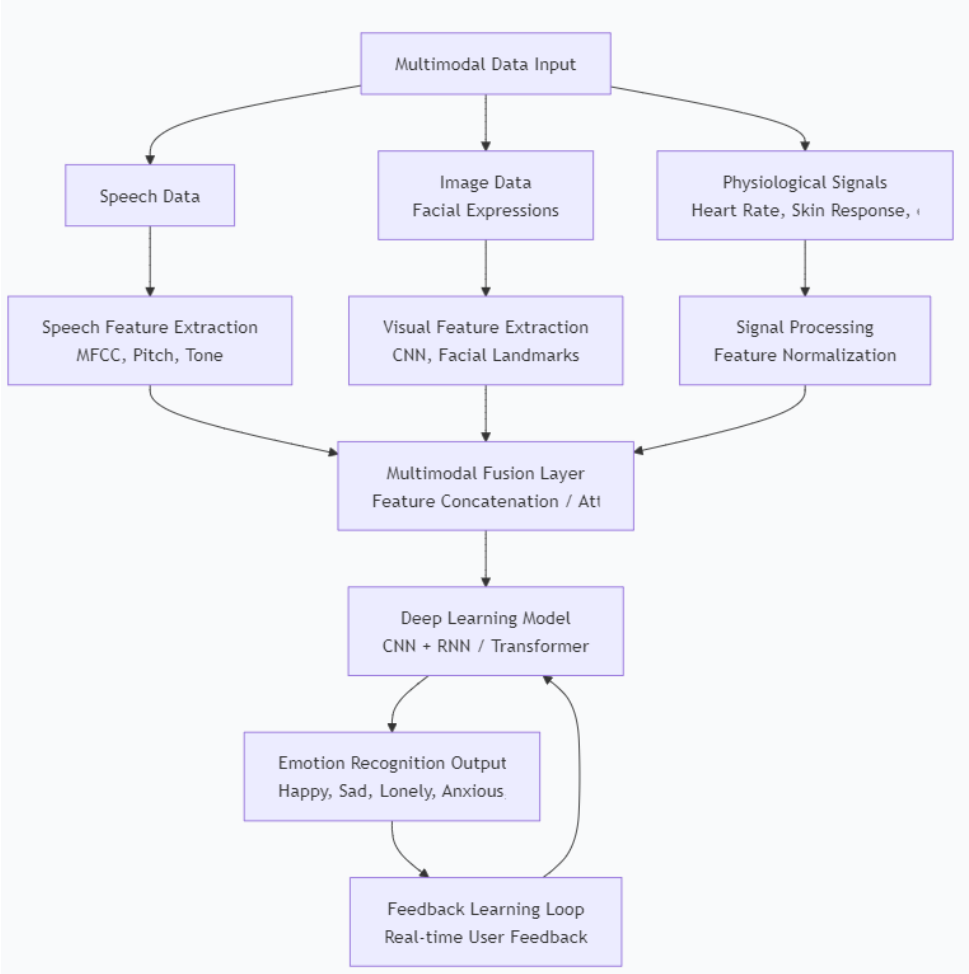

Figure ure.1. Flowchart of Multimodal Data Fusion-based Deep Learning Emotion Recognition Algorithm

4.1.3. Integrating Brain Computer Interface Technology to Improve Interaction Precision

Brain-computer interface technology directly decodes biological signals such as brain waves, enabling the immediate capture of the emotional state and intentions of elderly individuals. This technology effectively addresses the limitations of traditional emotional identification methods. When the language abilities of elderly individuals decline or they face physical constraints that hinder clear emotional expression, the brain-computer interface offers a minimally invasive communication method. By analyzing brain waves, robots can gain a deeper understanding of the emotional needs of the elderly and respond with greater precision. Upon identifying a specific emotion, the robot can promptly adjust its behavior and language to facilitate more natural and empathetic communication [12]. This enhances the authenticity and accuracy of emotional exchanges, improves the user experience for elderly individuals, helps them rebuild emotional connections with society and family, and contributes to psychological well-being and social integration.

4.2. Strategies for Enhancing Care Collaboration

4.2.1. Achieving Full Scenario Elderly Engagement and Emotional Interaction

In the daily lives of elderly individuals at home, robots can engage in instant dialogues with them using intelligent devices, monitor their emotional changes, and provide timely companionship and support. Additionally, in nursing homes and medical institutions, robots collaborate with staff to deliver customized emotional care and respond efficiently to specific emotional needs. Utilizing environmental perception technology, robots can identify different spaces and atmospheres where the elderly are located and automatically adjust their voice intonation and communication methods to address their emotional requirements. In social activities, robots act as communication partners for the elderly, fostering interaction among them and alleviating feelings of loneliness. To achieve this, it is essential to develop a more advanced emotional identification system that integrates natural language processing and machine learning technologies. This enables robots to continuously learn and refine their communication methods based on feedback from the elderly, ultimately providing comprehensive care. This approach ensures that elderly individuals experience emotional support and warmth in a variety of scenarios.

4.2.2. Constructing a Dynamic Human Robot Collaborative Care Strategy Matrix

Constructing a dynamic human-robot collaborative care strategy matrix is an effective approach to enhancing collaboration efficiency between elderly care robots and care staff. This matrix should encompass strategies tailored to various care scenarios, responsibility types, and individual needs. Each row represents a specific care scenario, such as home care, nursing home care, and medical institution care, while each column corresponds to care responsibilities, including emotional support, continuous monitoring, and routine care tasks. By integrating individual differences in older adults with emotional needs and practical care responsibilities, targeted collaboration strategies can be developed. Dynamic adjustment control relies on real-time data analysis and feedback. When emotional changes or new needs arise, the system promptly adjusts collaboration strategies and selects appropriate task allocation and interaction methods, thereby improving response speed and collaboration efficiency. Regular evaluation and optimization of the matrix ensure adaptability to changes in care environments and technological advancements, making human-robot collaboration more flexible and effective.

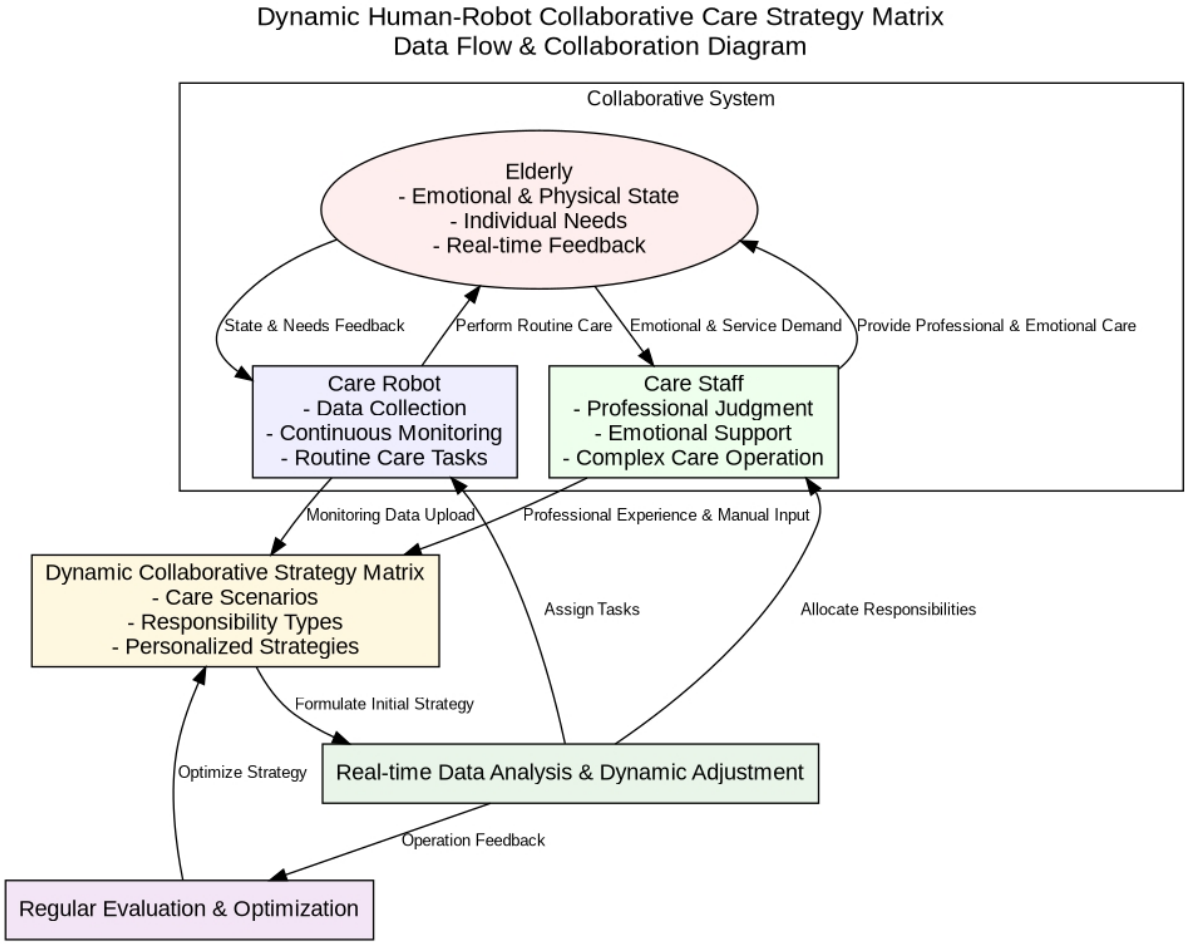

Figure ure.2. Architecture of Dynamic Human-Robot Collaborative Care Strategy Matrix and Data Flow

4.3. Ethical and Legal Safeguard Measures

4.3.1. Improving Data Authorization and Privacy Protection Mechanisms for Older Adults

To ensure compliant and secure operation of emotional interaction technologies in elderly care robots, improving data authorization and privacy protection mechanisms is critical. Clear informed consent procedures must be established to ensure that, before using care robots, older adults fully understand how their personal data will be collected, used, and processed. Explanations should use clear and accessible language so that older adults and their family members can understand relevant terms and exercise informed choice effectively. The principle of data minimization should be implemented by collecting only information necessary for specific functions, thereby reducing privacy risks associated with excessive data collection. During data storage and transmission, encryption and anonymization technologies should be applied to prevent unauthorized access and data leakage. Regular security assessments should be conducted to verify the effectiveness of data protection measures. Transparent data management mechanisms should be established so that older adults can understand how their data are used and track changes, enhancing trust.

4.3.2. Establishing Review Standards for Algorithm Fairness, Transparency, and Security

Developing review standards for algorithm fairness, transparency, and security is a crucial step toward ensuring the effective operation of AI algorithms used for emotional interaction in care robots. Fairness reviews should focus on identifying biases related to older adults of varying ages, genders, cultures, and physical conditions in the recognition and response to emotions. Standardized testing procedures must be established, and

algorithm performance across diverse datasets should be assessed regularly to ensure unbiased treatment. Transparency involves clearly explaining algorithm reasoning and decision-making processes, enabling users to understand how robots respond to emotional interactions. This fosters trust among older individuals and their families by providing insight into the underlying technical structures [13, 14]. Security reviews should address data protection, system vulnerabilities, and algorithm robustness to ensure safe operation under potential threats.

5. Conclusion

This study explores emotion recognition technologies and human-robot collaboration mechanisms to identify effective strategies for enhancing elderly care services. By integrating multimodal data with deep learning algorithms, the accuracy of emotion recognition is significantly improved, addressing the personalized emotional needs of older adults. The development of a dynamic human-robot collaboration strategy matrix clarifies role allocation between care staff and robots, optimizing care processes and enhancing both efficiency and outcomes. Ethical and legal safeguards, including improved data authorization and privacy protection mechanisms, ensure information security and respect for older adults, fostering trust in human-robot interactions. Future research should focus on strengthening the integration of technology and practical applications, investigating broader scenarios and diverse emotional interaction models, and advancing the comprehensive development of elderly care robots. These efforts aim to enhance the quality of life for older adults, support their physical and psychological well-being, and enable intelligent care robots to play an increasingly vital role in elderly care services, providing stable and high-quality support for society.

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