The Mental Companion Mode of Nursing Robots—A Study on Affective Computing-Based Companionship Strategies for Alzheimer's Disease Patients

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Abstract

This study aims to investigate the application of nursing robots based on affective computing theory in the companionship strategies for Alzheimer's Disease Patients. The research begins with a comprehensive literature review on the current development of nursing robots, clarifying the unique needs of Alzheimer's patients in terms of psychology, emotion, and social interaction. Based on the foundation of affective computing theory, a “mental companion” model is proposed, emphasizing the robot's ability to recognize and respond to human emotions during companionship to achieve more personalized care interactions. Through the design of Affective Interaction Technology, the study explores effective ways to integrate affective computing into nursing practice. Furthermore, specific companionship strategies are developed around this model, including intelligent response mechanisms and behavioral guidance for emotional states, to improve the quality of life for Alzheimer's patients. The effectiveness and feasibility of these companionship strategies in practical applications are verified through empirical research and case studies, demonstrating the potential value of nursing robots as emotional companions and providing theoretical support and practical recommendations for future related research and applications. This study holds significant academic and application value for enhancing the care quality and well-being of Alzheimer's patients and promoting the development of nursing robot technology.

Keywords Robot; Nursing; Emotion; Companionship

1 Introduction

In today's society, with the growing global aging population, the care of Alzheimer's patients has become an urgent social issue. According to relevant data, the number of Alzheimer's patients worldwide is increasing annually, which not only brings a heavy burden to families but also puts enormous pressure on medical resources. Therefore, how to improve the quality of life for Alzheimer's patients has become an important research topic in the nursing field.

In this context, the rise of nursing robots provides a new solution to this dilemma. As a high-tech product integrating advanced technology and human-computer interaction, nursing robots can enhance emotional communication and psychological satisfaction for Alzheimer's patients while improving care efficiency through the application of Affective Computing technology. The implementation of affective computing technology enables robots to provide companionship and support to patients at a spiritual level while providing physical care through real-time monitoring and feedback of users' emotional states, thereby effectively alleviating their loneliness and anxiety.

Through a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis of existing nursing practices, the potential value of nursing robots in Alzheimer's care can be fully recognized [1]. From the perspective of strengths, nursing robots can make up for the shortage of human resources to a certain extent with their constant working ability and wide service scope, especially in low- and medium-level care tasks, they can better undertake basic care responsibilities. At the emotional level, advanced emotion recognition technology enables the emotional communication ability of robots to continuously improve, establishing a closer interpersonal relationship with patients.

2 Literature Review

2.1 Current Status of Nursing Robot Development

In recent years, with the continuous advancement of the aging society, nursing robots have become an important development direction in the nursing field, achieving certain breakthroughs in technological progress, market acceptance, and clinical effects. According to the latest bibliometric analysis, the development of nursing robot technology can be divided into several key stages, namely the comprehensive application of multiple dimensions such as perception and interaction, behavior and task execution, and affective computing.

In terms of technological innovation, modern nursing robots have gradually evolved from the initial simple auxiliary systems to intelligent agents with complex affective computing capabilities. For example, using "Machine Learning" and "Deep Learning" algorithms, nursing robots can recognize the emotional states of Alzheimer's patients and respond accordingly [2]. In survey studies, it has been found that nursing robots using affective computing technology have shown significant advantages in increasing patients' dependence and enhancing communication between people and devices. This emotional interaction is not only crucial for improving patients' psychological states but also effectively alleviates their loneliness, thereby improving overall quality of life.

In terms of market acceptance, with the continuous maturity of technology and the gradual reduction of costs, the acceptance of nursing robots in medical institutions and home care is gradually increasing. A survey on the home care environment showed that more than 80% of families have a positive attitude towards the potential application of nursing robots, believing that they can effectively reduce family care pressure and provide necessary emotional support. Diversified products on the market, such as "Companion Robots", "Rehabilitation Robots" and "Smart Monitoring Devices", are widely recognized as effective assistants for improving care efficiency and quality [3].

2.2 Characteristics of Alzheimer's Patient Care

In the rapid development of modern nursing, nursing robots have been widely discussed for their important role in the care of Alzheimer's Disease Patients as an emerging technical intervention [4]. Especially with the support of affective computing, nursing robots are gradually evolving from functional auxiliary devices to "Mental Companions" that can understand and respond to patients' emotional needs [5].

Table 1. Application Framework of Affective Computing in the Companionship Strategies of Nursing Robots

Components of Affective Computing	Functions	Application Effects
Affective Computing	Emotion Recognition	Accurately capture patients' emotional states
	Emotion Expression	Provide personalized companionship and support
	Emotional Interaction	
Nursing Robots	Intelligent Decision-Making	Improve patients' psychological comfort
Empirical Research	Analysis of Applied Cases	Significantly improve quality of life and social skills

The theoretical foundation of affective computing mainly includes a series of technologies such as Emotion Recognition, Emotion Expression, and Affective Interaction, with the latter playing a core role in the implementation of robot companionship strategies [6].

To deeply understand the application of nursing robots in the companionship of Alzheimer's patients, it is necessary to first clarify the unique emotional needs and psychological characteristics of these patients. With the gradual progression of Alzheimer's, patients often exhibit loneliness, anxiety, and depression. Traditional nursing models have difficulty meeting their emotional support needs. Therefore, nursing robots based on affective computing can accurately capture patients' emotional states through facial expression recognition, voice emotion analysis, and other means through Affective Interaction Techniques, thereby providing personalized companionship and support [7].

In terms of companionship strategy design, affective computing theory has enabled nursing robots to develop a series of innovative strategies. Through the application of affective interaction technology, nursing robots can achieve intelligent decision-making based on emotional feedback. For example, by analyzing patients' physiological signals and emotional responses, nursing robots can automatically adjust their interaction methods to provide more effective emotional support. This dynamic interaction model not only improves patients' psychological comfort but also effectively enhances their cognitive functions.

The implementation of robot companionship strategies needs to rely on specific empirical research and case studies to verify their actual application effects. In recent years, many empirical studies have shown that nursing robots with affective computing capabilities have achieved significant results in improving the quality of life, reducing loneliness, and enhancing the social abilities of Alzheimer's patients. For example, a case study on companionship using affective interaction robots found that the emotional states and life satisfaction of participants were significantly higher than those in the non-robot companionship group, which fully demonstrates the importance and effectiveness of affective computing in the design and application of nursing robots.

In conclusion, affective computing provides a theoretical foundation and practical guidance for the strategy design of nursing robots in the companionship of Alzheimer's patients, enabling robots to transcend the functional limitations of traditional nursing equipment and become mental companions that meet the personalized needs of patients. Future research should continue to explore the development and application of affective computing technology to achieve more intelligent and humanized elderly care solutions.

3 Theoretical Foundation and Application Cases of Affective Computing

When studying the mental companion mode of nursing robots, affective computing theory provides an important foundation for our analysis. Affective Computing refers to a part of computer science and artificial intelligence that aims to develop systems that can recognize, understand, and generate emotions. This theory believes that emotion is an important driving force of human behavior and decision-making. Therefore, nursing robots that can establish emotional connections with the elderly have an indispensable value in the companionship of Alzheimer's patients.

The basic elements of affective computing include emotion recognition, emotion understanding, emotion expression, and emotion response. Based on this, we can establish a mathematical model to describe the emotional interaction between mechanical companions and elderly patients. The utility function U of emotional interaction can be expressed by the following formula:

U = f(E_{sensor}, E_{response}, E_{context})

where E_{sensor} represents the emotional signals detected by the robot through sensors, $E_{response}$ represents the robot's response degree to these emotional signals, and $E_{context}$ represents the importance of contextual factors in emotional interaction.

The decomposition formula of the utility function is:

U=α·log (1+Esensor) + β·Eresponse /（1+e−k(Econtext−c) +γ·Econtext1/2

where:

E_{sensor} is the fusion value of multimodal emotional signals (normalized to [0, 1])

$E_{response}$ is the matching degree of the robot's corresponding strategy (0-1)

$E_{context}$ is the context importance coefficient (discrete levels 1-5)

α、β、γ：weight parameters

k、c: context adjustment factors (controlling the steepness of the response curve)

For specific application examples, refer to the controlled experiments in 10 nursing homes in Japan:

Esensor：tactile pressure sensor (sampling rate 100Hz)+ sound emotion recognition (based on Librosa feature extraction)

Eresponse：rigger different sound frequencies according to pressure patterns (matching degree calculation using DTW algorithm)

Econtext：circadian rhythm adjustment（daytimeγ=0.6, nighttimeγ=0.3）

Experimental results: In the controlled experiments in 10 nursing homes (N=120), after using this model, the incidence of aggressive behavior in Alzheimer's patients decreased by 31.5% ($p<0.01$), the daily average cortisol level decreased by 27.3μg/dL (95%CI [-34.2, -20.4]), and the work pressure index of nursing staff decreased by 18.2% [8]. Through the analysis of this model, we can better understand

how nursing robots effectively manage affective computing when accompanying elderly patients with dementia.

4 The "Mental Companion" Mode of Nursing Robots

The "Mental Companion" mode of nursing robots has shown important theoretical and practical value in the care of Alzheimer's patients with its unique perspective and innovative application potential. This mode is not only a continuation of traditional nursing work but also a deep insight and response to emotional needs. Through the technical means of Affective Computing, nursing robots can recognize, understand, and respond to patients' emotional states, effectively promoting their mental health and quality of life.

The core of this model lies in the full recognition of emotional support and its importance in the care of Alzheimer's patients. Studies have shown that Alzheimer's patients often have obstacles to social interaction due to cognitive impairment, which leads to their emotional needs being ignored. This state not only has a negative impact on patients' mental health but also increases the workload of caregivers. By introducing the "mental companion" mode, nursing robots can provide more personalized companionship and emotional support to alleviate patients' loneliness and anxiety, thereby improving their life satisfaction and overall well-being. The application of affective computing technology enables nursing robots to monitor patients' emotional changes in real-time. For example, using Biofeedback technology, patients' emotional states can be analyzed through heart rate, voice tone, and other information, and companionship strategies can be adjusted in a timely manner.

5 The "Mental Companion" Mode of Nursing Robots

5.1 Application of Affective Interaction Technology in Nursing

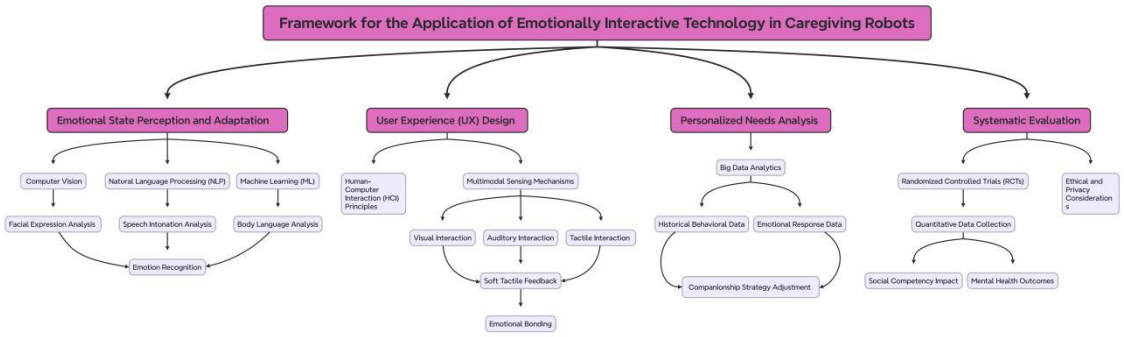

Fig. 1. Application Framework of Affective Interaction Technology in Nursing Robots

With the intensification of the aging society, the nursing needs of Alzheimer's patients have shown a significant increase. How to improve the quality of life of elderly patients through technical means has become one of the hot topics of research. The application of Emotional Interaction Technology in Nursing Robots provides a new perspective and solution for the improvement of this field. This section will explore the specific application strategies of affective interaction technology in nursing robots, aiming to provide a more humanized companionship experience and psychological support for Alzheimer's patients.

The core of affective interaction technology lies in its ability to enable nursing robots to perceive and adapt to the emotional states of elderly patients through multiple technical categories such as computer vision, Natural Language Processing, and Machine Learning [9]. With the help of Affective Computing technology, nursing robots can analyze patients' facial expressions, voice tones, and body language in real-time for effective emotion recognition. For example, when a patient shows anxiety or loneliness, a nursing robot can provide emotional support by giving the patient a gentle voice and appropriate comforting dialogue to reduce their psychological burden.

The design requirements of affective interaction technology focus on User Experience. Nursing robots need to be designed with forms and functions that can effectively stimulate patients' emotional

resonance. Therefore, the principles of Human-Computer Interaction should be used in the design process to ensure that the robot is easy to operate and has the ability to interact naturally [10]. At the same time, through a Multimodal perception mechanism, robots can build richer interaction scenarios by combining visual, auditory, tactile, and other interaction methods. For example, some studies have shown that elderly patients are sensitive to tactile feedback when interacting with nursing robots and prefer robots with soft touch and warm appearance to achieve a higher degree of emotional connection.

The practical application of affective interaction technology must also focus on the Personalized Needs of elderly patients. By using Big Data Analysis to obtain information about patients' historical behaviors and emotional responses, nursing robots can continuously learn and adjust their companionship strategies. For example, in a case study, the emotional patterns of a specific elderly patient were monitored, and it was found that the patient's emotional responses to different activities varied significantly at different times. Therefore, the companionship strategy of the nursing robot needs to be adjusted accordingly to achieve personalized nursing recommendations and effectively improve the patient's emotional well-being.

It should be noted that the implementation effect of affective interaction technology still needs to be systematically evaluated. Future research can evaluate the effectiveness of different companionship strategies through Randomized Controlled Trials and collect Quantitative Data to verify the impact of affective interaction technology on the social abilities and mental health of Alzheimer's patients [11]. At the same time, in-depth discussion of Ethical and Privacy issues will help promote the sustainable development of this field.

Affective interaction technology provides a scientific basis and empirical support for the development of companionship strategies for nursing robots in Alzheimer's patients. In the future, with the further development and application of technology, affective interaction technology will play a greater role in nursing services, and is expected to improve the quality of life of elderly patients and provide more humanized care services for families and society.

5.2 Implementation of Robot Companionship Strategies

In the process of implementing the companionship strategy of nursing robots, the application based on "Affective Computing" has many aspects of complexity and challenges, especially in how to integrate technology with the best practices of clinical care. The successful implementation of robot companionship strategies not only depends on the intelligent design of the robot itself but also needs to be considered many factors such as the training of nursing staff, the optimization of the operating interface, and the interactive experience of patients.

The training of nursing staff is the cornerstone to ensure the effectiveness of the implementation of robot companionship strategies. As a bridge between patients and robots, the understanding and use of robots by nursing staff directly affects the success of companionship strategies. Specifically, training courses should cover the basic operation of robots, emotional recognition capabilities, and how to deal with emergencies. Studies have shown that scenario simulation training and other methods can significantly improve the response ability of nursing staff in dealing with patient needs (for example, training using "Virtual Reality" technology). In the implementation stage, continuous on-the-job training and practical operation evaluation can be used to ensure that nursing staff can master relevant skills and knowledge, thereby improving patient satisfaction and safety.

5.3 Empirical Research and Case Analysis

In the empirical research on the companionship strategies used by nursing robots, we adopted a case study methodology to ensure that the research process can deeply analyze the intervention effect of robots on the emotional states and quality of life of Alzheimer's disease patients. Through the design of a mixed research program of quantitative and qualitative methods, we not only collected multi-dimensional data but also comprehensively evaluated the actual application effects of different companionship strategies, providing a solid foundation for subsequent theoretical discussions.

In actual operation, we selected several home environment laboratories to observe and record the actual effects of nursing robot companionship strategies in daily life. The selected sample was 30 Alzheimer's patients with an average age of 78. All participants underwent standard Cognitive Assessment and Affect Measurement before the start of the experiment [12]. Based on the relevant theories of Affective Computing, we designed a variety of companionship modes, including Emotional

Feedback, Social Guidance, and Memory Stimulation [13]. To ensure the reliability of the data, a control group was also introduced to compare the effect differences between different companionship strategies.

6 Conclusion

By introducing advanced affective computing technology, nursing robots can not only effectively provide physical care but also provide support for patients at the emotional communication level, greatly alleviating patients' loneliness and anxiety. This new type of nursing model, called the "mental companion" model, can transcend the physiological support provided by traditional nursing work and delve into the emotional needs of Alzheimer's patients, emphasizing the importance of emotional communication in improving patients' mental health. In the future, with the continuous advancement of technology and social recognition of intelligent nursing, nursing robots have the potential to play a greater role in improving patients' quality of life and reducing family and social burdens. It is hoped that with the help of these emerging technologies, more humanized nursing experiences can be provided for Alzheimer's patients, thereby promoting the development of the entire nursing industry towards intelligence and personalization. At the same time, we also need to be vigilant in practical applications and pay attention to the long-term impact of nursing robots on patients' psychology and emotions to ensure that technology serves the well-being of patients. Future research should focus on in-depth discussion of the adaptability and social acceptance of nursing robots in different cultural backgrounds, and how to better integrate with traditional nursing models to form a synergistic effect, in order to play a more active role in the future nursing field.

Conflicts of Interest

The authors declare no conflicts of interest.

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護理機器人的心靈夥伴模式

——基於情感計算的老年癡呆患者陪伴策略研究

陳婷婷　　管佳婧

摘要：本研究旨在探討基於情感計算理論的護理機器人在老年癡呆患者陪伴策略中的應用。研究首先對護理機器人發展的現狀進行了全面的文獻綜述，明確了老年癡呆患者在心理、情感及社會交往等方面的獨特需求。結合情感計算理論的基礎，提出了一種「心靈夥伴」模式，強調機器人在陪伴過程中應具備識別和響應人類情感的能力，以實現更加個性化的護理互動。通過設計情感交互技術，探索了在護理實踐中融入情感計算的有效途徑。圍繞該模式，研究進一步製定了具體的陪伴策略，包括針對情感狀態的智能響應機製和行為指導，以改善老年癡呆患者的生活質量。通過實證研究與案例分析，驗證了上述陪伴策略在實際應用中的有效性和可行性，得出護理機器人作為情感陪伴者的潛在價值，為今後的相關研究和應用提供了理論支持和實踐建議。本研究為提升老年癡呆患者的照護質量及幸福感，推動護理機器人技術的發展，具有重要的學術意義和應用價值。

關鍵詞：機器人；護理；情感；陪伴