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Development of Robots for People with Dementia: Technologies and Applications

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ABSTRACT

Due to the rapid aging of the population and the impact of coronavirus disease 2019 (COVID-19), medical and long-term care facilities have undergone tremendous changes, and the condition of older adults with dementia is becoming critical. They lack adequate treatment, companionship, and care. This research explores how the development of robots can assist people with dementia. It is under a structure that includes sensing components, decision-making components, and structural components. The paper reviews methods to meet the needs of people with dementia and summarizes related applications of robotics, including diagnosis assistance, treatment assistance, health care assistance, and rehabilitation assistance. An intelligent wheeled robot system equipped with multiple applications was proposed to provide comprehensive services for people with dementia and committed to their activities of daily living. The results and discussion of this study are proposed to assist engineers and clinicians in related fields to design and utilize the robot for people with dementia.

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INTRODUCTION

Demantia is a clinical syndrome that can be treated with psychosocial and physical intervention (Geldmacher and Whitehouse, 1996). A variety of factors, such as old age, genetic variations, depression, and lifestyle factors, may increase the risk of developing the disease (Kuźma et al., 2018; Stephan et al., 2018; Licher et al., 2019). The psychological and physical symptoms of dementia are mainly manifested as perceptual disorders, cognitive disorders, emotional deficits and behavioral disorders (Deardorff and Grossberg, 2019), which increases the difficulty and cost of care. According to the World Alzheimer Report 2015 (Prince et al., 2015), there will be over 50 million people worldwide living with dementia in 2020. With the increase in the lifespan of the global population, the number of patients suffering from dementia has almost doubled every past 20 years and is expected to be the same in the future. However, the diagnosis of dementia requires a long-term, rigorous clinical evaluation by doctors. In view of the lack of medical care, it is difficult for patients from economically backward areas to receive clear diagnoses or care (Abbott, 2011; Jia et al., 2020). According to DSM-5 (2013), the classifications of dementia have been proposed as Alzheimer’s disease (AD), dementia with Lewy Bodies (DLB), frontotemporal dementia (FTD), vascular dementia (VD), and other dementias. Alzheimer's disease and vascular dementia are considered Alzheimer's disease is the most common cause of dementia, accounting for an estimated 60% to 80% of cases (Alzheimer's Association, 2021).

In response to the outbreak and spread of the COVID-19, many countries have implemented many restrictive measures that refrain doctors from making medical examinations and diagnosing patients, and communication between patients and nursing staff has caused corresponding adverse effects. Thus, facing various challenges, such as the increased number of patients, the difficulty of diagnosis, and the expense of care, the situation of people with dementia is becoming increasingly handicapped.

The psychological needs of patients should be paid attention to and to maintain the concept of their personalities, which may be achieved by various types of robots. In the past three decades, the application of robots has expanded from the industrial field to individual users. Early robots for people with dementia, such as AIBO (Tamura et al., 2004), Paro (Wada et al., 2008), and Rassle (Zheng et al., 2018), were designed as cute pets that replaced real animals that evoke emotions and interact in sophisticated multisensory ways (Mordoch et al., 2013). Subsequently, robots with more functions were developed, such as MARIO (Casey et al., 2016) and Ryan (Abdollahi et al., 2017), which have complex interactions with humans and greater degrees of freedom (DoFs). Also, there are some robots partially replacing care workers, such as AMIGO (Paletta et al., 2019) and Baxter (Cooney et al., 2020), that can provide dementia people with health guidance or help with daily living activities. The ability of robots to adapt to the environment is advancing, benefiting from sophisticated sensors, robust control algorithms, and powerful high-speed computers. Therefore, the operation of the robot is becoming simpler and more intelligent.

The main purpose of this paper is to discuss the technical methods that can assist patients in early stage of dementia and the robot applications involving these methods. In view of the survey of related papers, a smart robot was proposed. This article also aims to answer the following questions: What kinds of robots do mild dementia people need, and what kind of hardware and software design can we develop? Robots can assist in dementia diagnosis, treatment, and healthcare to improve patients' quality of life and maintain functional daily activities.

Design of Robot for People with Dementia

To provide people with dementia functionality and convenience, robots must satisfy the technology acceptance model (TAM, (Lee et al., 2003)): perceived ease of use (PEOU) and perceived usefulness (PU). PEOU ensures that people with dementia are willing to accept the help from the robots and that the robots are easy to use. PU reflects the positive effects of robots on people with dementia.

PEOU is mainly manifested in the humanized design of robots, including appearance design and graphical user interface (GUI) design, and it is equipped with a decent number of sensors, which ensures that the robot will be capable of adapting to new technologies and functions. Although many robots have different design motives and concepts, they still have a common overall architecture. The classical structure of robots for people with dementia is summarized in Fig. 1, which integrates sensing components, decision-making components, and structural components.

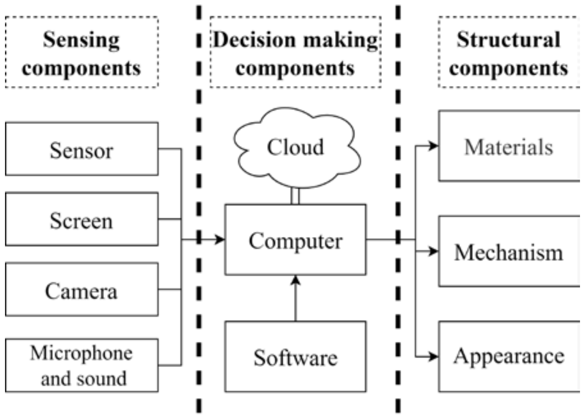

Fig. 1. The classical structure of robots for people with dementia.

Sensing components collect information about the state of the robot and its environment and transmit the information to the outside world. Decision-making components process and analyze the signals through the software of different architectures and transmit the signals and issue instructions. Structural components support the various mechanisms of the robot and realize specific movements. A comparison of the robots for people with dementia is shown in Table 1.

Table 1. Comparison of robots for people with dementia.

Name	Reference	Sensing Components	Decision Making Components	Structural Components
Paro	Wada et al., 2008 (First version, 2003)	Surface tactile and posture sensors, temperature sensors, microphones, and light sensors.	It can recognize and react when receiving different stimulation.	A seal pup with a cute figure and soft texture.
Ryan	Abdollahi et al., 2017	An RGBD camera, and a touch screen.	It can communicate with users and interact through games.	A conversational humanoid robot without lower limbs.
Rassle	Zheng et al., 2018	A camera, a microphone, and tactile sensors.	It provides sound and motion feedback during the interaction.	A teddy bear with soft furry skins.
Baxter	Cooney et al., 2020	An RGBD camera.	It provides exercise analysis and exercise guidance.	A humanoid robot with a pair of robotic arms.

Sensing Components

As the needs of people with dementia are numerous and complicated, design considerations also have many aspects. The first thing to consider is designing the application scenario for the robot and selecting sensors suitable for this hypothesis. The sensors mounted on the robot can be subdivided into two categories: perception of the real world and human–robot interaction (HRI). Multiple sensors, such as light detection and ranging (LiDAR), inertial measurement unit (IMU), camera, and ultrasound, are used for simultaneous localization and mapping (SLAM), which can realize navigation, obstacle avoidance, cruise, monitoring, and other functions. These functions assist the robot in adapting to various complex environments and quickly responding to unexpected events.

The sensors related to HRI include the camera, screen, microphone, sound, and pressure. The data derived from these sensors support and extend the applications of computer image vision, speech recognition, and natural language recognition. There are many types of cameras. Monocular cameras are inexpensive and can provide real-time images. Stereo and RGB-D cameras add depth data based on RGB images. In addition, sensors that monitor the physical condition of the participants are also used, such as fall monitors, help monitors, breath monitors, and heart rate monitors, which can ensure the participants are not in danger.

Decision-Making Components

Robots for people with dementia use different ways of responding to users, which manifest as different robot behaviors. Modeled on human neural reflexes, robot behaviors can be roughly divided into two categories: unconditioned reflex behavior and conditioned reflex behavior; though they are all in accordance with the implementation of the written program to give feedback to the sensor signal, unconditional reflex behavior, such as responding with a scream when touched and alerting when the battery is low, has a single function but requires less calculations, while conditioned reflex behavior requires a better processor for complex arithmetic processing, such as image processing, motion planning, and machine learning. Considering the size and cost of the robot, the internal computer may not be able to handle all the functions. Thus, the cloud is used to enhance the capabilities of the computer, which can be summarized in the following several ways: data storage, processing data, and analysis.

Structural Components

The design focus of the structural parts of the robot is divided into material, mechanism, and appearance. Considering the design for the older adults, robustness and hygiene are important factors for use. Hard and durable materials are used for internal support. The outer surface of the robot is green and sterile materials, such as cotton, leather, plastic, and other materials, which depends on whether the robot needs to be in contact with the user for a long time. The design of the mechanisms is limited by the size of the robot. Some robots only have vibrating motors to provide tactile feedback. However, users will easily lose interest in interacting with robots due to single feedback. Therefore, complex mechanisms with greater degrees of freedom are more attractive to users. The last thing to consider is that the appearance design should be as attractive as possible. The appearance of baby animals can reduce the patient's indifference and increase his or her willingness to interact.

APPLICATIONS OF ROBOTS FOR PEOPLE WITH DEMENTIA

The needs of people with dementia can be summarized as diagnosis assistance, treatment assistance, health care assistance, and rehabilitation assistance. Related technical methods are listed to discuss how to help patients improve their quality of life, which also reflects the PU of the robot.

Diagnostic Assistance

Diagnosis of prodromal AD is vital for the patient to express treatment preferences and reduce the risk of hospitalization, and it can also enable the patient to reduce the disease as soon as possible. By taking specific drugs, they can delay the conversion of mild cognitive impairment (MCI) to AD (Elahi and Miller, 2017).

According to Elahi and Miller (Elahi and Miller, 2017), the most definitive classification system for people with dementia is based on the underlying pathology categorized according to the observed accumulation of abnormal protein aggregates in the glia and neurons. These aggregates disturb molecular processes, cellular functions, cell survival, and the ensuing disruption of large-scale neural networks that support cognitive, behavior, and sensorimotor functions. The patient's various functions are degraded and lost, and corresponding symptoms are derived. The diagnosis of AD is complicated and difficult. For this reason, many technical methods have been developed to assist in diagnosis. Dubois et al. (Dubois et al., 2007) showed that AD can be diagnosed by the status of biomarkers and episodic memory impairments. Gill et al. (Gill et al., 2020) predicted dementia from neuropsychiatric symptoms and neuroimaging data using machine learning (ML), reporting 95% confidence intervals. These pathological analyzes are relatively precise, but they require professional equipment and a doctor's clinical record. However, many researches do not concern about the internal working of ML models and the relationship between clinical record and ML features, which hinders the clinical use of the theory. Opening the black box of machine learning and working within an ethical framework can assist clinicians to evaluate the advantages of the ML model and utilize the results predicted by the model.

Also, varying degrees of cognitive impairment, including difficulty remembering new information and forgetfulness, will increase the risk of prodromal AD, which is reflected in the abnormal symptoms of the patients. Therefore, Carvalho et al. (Carvalho et al., 2017) developed a clinical decision support system for aiding diagnosis by collecting the user's behaviors. Chien et al. (Chien et al., 2019) developed a system that uses voice signal analysis to monitor or evaluate the state of the user. In other words, the evaluation system can be based on different kinds of input, such as speech analysis, behavior analysis, or physiological analysis. The robot can integrate various sensors to collect these data, so that these evaluation systems can provide auxiliary diagnosis for users, especially older adults living alone, which makes the evaluation objective, flexible, efficient, and convenient.

Since therapist-led exercise has proved accessible for reducing degeneration in the physical health of dementia patients (Hirsch, 2013), more research on a rehabilitation robot system has been developed in recent years. Cooney et al. (Cooney et al., 2020) believed that robots could play a perfect role as exercise coaches for people with dementia. They proposed a robot exercise coach for people with dementia, which was required to meet three requirements: exercise analysis, interruption detection, and enjoyable design. To be more acceptable to people with dementia, robots with a small size and an adorable appearance were used for rehabilitation trials. Hamada et al. (Hamada et al., 2016) proposed a rehabilitation system based on a humanoid robot Palro, and two kinds of rehabilitation activities were included in the study: a single elderly player played a physical activity game with Palro, and multiple players exercised with Palro, respectively. Besides Palro, another humanoid robot, Pepper, was used to encourage exercise in dementia patients by Schrum et al. (Schrum et al., 2019). During the research test, Pepper could not only demonstrate the exercise, but also verbally encourage participants to catch up with the tempo. However, the participants' movements were not mentioned here.

Treatment Assistance

Treatment plays a significant role in maintaining the daily functions of people with dementia. However, treatment cannot completely cure the disease, and there is currently no effective drug to cure dementia. The significance of treatment is to allow patients to delay the degeneration of the disease as much as possible, as well as to alleviate the symptoms and negative effects of dementia.

This section discusses achieving the treatment goals of nonpharmacologic approaches, including prevention, management, or reduction of behavioral or cognitive abnormal behavioral occurrences that slow down or delay the decline of brain activity. Common nonpharmacologic approaches are listed as follows: physical activity, cognitive and social activity, diet and nutrition, smoking cessation and alcohol abstinence, and so on (Gitlin et al., 2012; Yaffe and Hoang, 2013).

Ahlskog et al. (Ahlskog et al., 2011) shows the habit of regular exercise can slow down the degeneration of the brain, reduce the decline of physical function, and improve the quality of life. Various exercises, especially aerobic exercises, can reduce cognitive impairment, prevent degeneration and loss of neurons, and reduce the risk of dementia. Animal studies have shown that exercise can promote neuroplasticity and improve learning outcomes through various biological mechanisms. Cruz-Sandoval et al. (Cruz-Sandoval et al., 2018) explains that exercise can also help patients improve balance, muscle strength, endurance, flexibility, and posture. It was also introduced that the use of robots can assist the older adults in exercising.

Cognitive activity can reduce the symptoms of dementia, in which factors such as education can serve as a buffer against the effects of neuropathologic damage associated with dementia (Yaffe and Hoang, 2013). Also, cognitive training can reduce the risk of dementia and delay cognitive and language decline in the early AD stage (Nousia et al., 2018). Some researches (Sondell et al., 2018; Rouse et al., 2019) showed that social activities have a significant impact on brain health and cognitive function. Regular social activities can slow down the cognitive decline caused by dementia; companions can meet the needs of cognitive training and social activity, since more than a third of people with dementia have expressed that loneliness is a significant factor affecting their daily life (Kane and Cook, 2013).

Some applications cover multiple non-pharmaceutical methods, such as virtual reality (VR) and augmented reality (AR), which provide entertainment, fight against loneliness, and reduce labor costs. Sobral et al. (Sobral and Pestana, 2020) used quantitative performance indicators to determine the relevance of VR in improving dementia people health. Specific measures to assist people with dementia include returning scenes to awaken memories, playing visual perception games to improve cognitive ability, and providing passive or active interactions to maintain social interaction.

Due to the adorable appearance and interactive functions that most companion robots have, they gradually become a more acceptable choice for people with dementia to alleviate loneliness. The appearance and behavior of a pet-like robot may arouse curiosity and facilitate interaction in people with Dementia (Lu et al., 2021). Pike et al. (Pike et al., 2021) proposed research proving that a robot cat can play a significant role in enhancing well-being and communication ability. A robot cat has also been proven to relieve the symptoms of dementia. In their study, a companion robot cat produced by Ageless Innovation was used to produce a case study. The robot cat, which was battery-powered, could not be programmed, and it could operate in two modes: mute or sound. To produce the proposed method, a well-trained researcher brought a robot cat to each participant with dementia. After the robot cat was accepted by the participant and their family, the participant lived with the robot cat for some time. The results of the case study were evaluated based on four themes: acceptance, distraction, communication, and connecting with others. Some interviews were also conducted to corroborate their conclusions. In the end, the team announced that the robot cat was able to improve the emotional stability and social behavior of the patient. Apart from a robot cat, a companion robot, PARO, has also been used to treat dementia. PARO, a robot seal equipped with a tactile, light, audition, temperature, and posture sensor, was developed by Advanced Industrial Science and Technology (AIST). The robot was able to perceive changes in the environment and the people interacting with it. Furthermore, PARO could remember and learn from people's previous behaviors, which enhanced its interactivity. Lillian et al. (Hung et al., 2021) proposed that PARO could have a positive impact on people with dementia in hospital care. According to their study, the robot seal was mainly helpful for psychosocial needs, including inclusion, identity, attachment, occupation, and comfort of people with dementia. However, whether the positive effect could be maintained remains uncertain. Another study conducted by Pu et al. (Pu et al., 2020) showed that PARO was not only able to improve the mood stability of people with dementia but could also relieve chronic pain. Some limitations of the robot, including voice, weight, and programming problems, were also thought to be improvable. Nariai et al. (Nariai et al., 2021) proved that robot-assisted recreation (RAR) had a positive effect on dementia patients.

Other lifestyle habits will also affect the state of people with dementia, such as diet and nutrition, alcohol abstinence, and smoking cessation. Good living habits help maintain people's physical and mental health and reduce possible complications.

Health Care Assistance

People with dementia may face many symptoms, such as forgetfulness, loss of judgment, partial loss of memory, decreased ability to express, and loss of the concept of time and place. If the above situation reaches a more intense level, it may cause the danger of falling, getting lost, being deceived, accidents, etc. Therefore, patients will have greater risks in daily life, and how to avoid these risks and maintain instrumental activities of daily living (IADL) is worth exploring.

The care of patients with mild to moderate dementia must provide them with a comfortable and safe environment. For example, giving them a familiar living environment, putting up reminders in obvious places, and encouraging patients to engage in more social activities. For severely ill patients, long-term care or nursing facilities need to be arranged. Going to the toilet, bathing, eating, and so on might be dangerous for these patients. The staff may need to pay extra attention to water temperature and falling issues. It is also necessary to provide supervision on patients' medication reminders. Also, patients with dementia have roaming behavior, so they may not be able to return home because they get lost when they go out. Therefore, patients must be supervised and under proper care to avoid going out on their own. Regardless of the patient's condition, it is meaningful to maintain the patient's muscle strength. After the physical examination of people with dementia, the robot can instruct them to exercise appropriately to maintain muscle strength, which can effectively maintain physical functions and reduce the caregiver's burden.

Correspondingly, robots that assist caregivers or provide direct care have been developed to improve the quality of life of people with dementia. Due to the insufficiency of healthcare staff for dementia patients, moving healthcare services from healthcare institutions to the home seems to be a promising trend, which could facilitate older adults aging in place. As a result, telerobotic systems that allow caregivers to provide dementia care remotely have emerged. With the help of various sensors carried on the robot, it is easier for the nursing staff to observe and obtain the physical conditions of the people with dementia. Lv et al. (Lv et al., 2020) proposed a telerobotic system that consists of three main parts: caregivers, assistive robots, and dementia patients. The caregiver, which is the teleoperator, is the person who remotely controls the assistive robot. Also, the dual-arm collaborative robot YuMi with seven degrees of freedom of each arm is chosen as the assistive robot. The system was proposed to offer local help by a robot arm controlled by a remote caregiver to improve the quality of daily life of patients.

DEVELOPMENT OF A ROBOT FOR PEOPLE WITH DEMENTIA

People with dementia usually have the following symptoms: social withdrawal, personality change, behavioral disorientation, memory loss, poor judgment, etc. Due to the different living habits of people with dementia, traditional robots cannot fully handle complex situations and complex operations. To improve these patients' quality of life and maintain functional daily activities, we propose a smart mobile robot named MOBI to be an assistance for dementia treatment, health care, and rehabilitation. This robot is mainly designed for mild AD patients to build a comfortable and safe environment. Thus, many parts work together to contribute to this. The camera checks whether people have abnormal movements; ultrasonic sensors and SLAM detect physical collisions and ensure the robot's movements safety; and the computer summarizes environmental information to provide comfortable feedback (Ting et al., 2020).

Hardware Platform

To demonstrate our applications of robots for the care of patients with dementia, we developed a smart mobile robot MOBI with dual arms and hands (shown in Fig. 2). The robot can express complex emotions with a 7 inches LED touch pad screen and six DoFs arms. MOBI is equipped with two Intel RealSense D435i depth cameras, which can collect RGB and depth streams simultaneously. In order to apply MOBI to complex environments, it is equipped with a laser sensor with a 180 degrees' visibility range used for location and path planning purposes.

Fig. 2. The hardware of the robot for PwD.

MOBI is equipped with three computers: a NVIDIA Jetson AGX Xavier, an Intel Core i7 LGA1151 CPU Win10 computer and a Linux industrial personal computer. The three computers use different operating systems and perform their own functions. The Win10 computer is the backbone of our mobile robot. It handles controlling dual arms and hands and connecting other systems. NVIDIA Jetson AGX Xavier is famous for its powerful GPU computation for deep learning; thus, we deployed the machine learning model there. The Linux industrial PC, located at the bottom of our mobile robot, controls navigation. Simultaneous localization and mapping (SLAM) systems are implemented by this component. The system diagram of the robot MOBI is shown in Fig. 3. Besides, the use of TCP/IP socket connection allows communication between the different systems. Theoretically, a high-computing computer can be used instead. However, using multiple computers with different operating systems can have advantages, such as avoiding interference and conflicts between tasks. Wu et al. (Wu et al., 2010) evaluated TCPs on a 10Gbps network, which supports that it is capable of handling bulk data transfer with stability and speed.

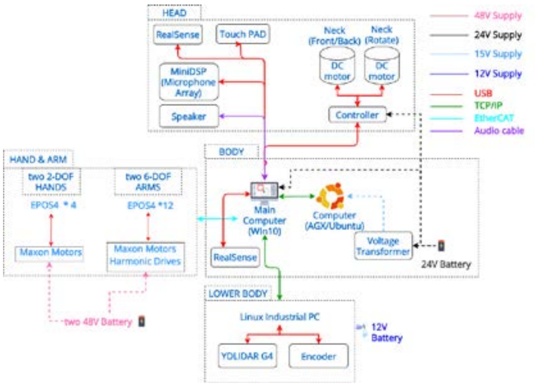

Fig.3. The system diagram of the robot MOBI.

Software System and Functions

According to PEOU and PU, a robot must have basic technologies and functions to meet the common needs of people with dementia, while allowing the robot to add new and extended functions at any time. An open distributed system helps increase the freshness of users and encourages them to use robots for longer periods. This software system connects various components as a whole and consists of four technologies:

1. **Engagement and intention detection.** To identify people in need of help in a complex environment, engagement and intention detection must be used in the system. Engagement is obtained through three information signals and a hidden Markov model (HMM). And we use the emotions of the interactor to infer further potential intentions. The intention model is obtained through two information signals with three sentiment indexes and an HMM (Huang and Lu, 2020).
2. **Navigation and SLAM.** The robot must know the overall environment and the location of obstacles to guide or lead the user. In addition, the use of different sensors can ensure safety by detecting potential hazards.
3. **Communication Systems.** The robot uses the computer and the attached router as the core of data interaction, and performs real-time information processing and feedback.
4. **HRI.** A well-designed HRI can help to reduce the risk of accidents and injuries. For example, the walking speed of the robot must be able to change dynamically depending on the environment or obstacles (Chung et al., 2009).

With the combination of these technologies, the robot can provide more specific functions and capabilities, as shown below, which were developed or are in development:

1. **Diagnosis assistance.** The robot detects the

user's cognition status and behavior, and constantly evaluates his mental status by ML analysis. By comparing historical databases, auxiliary diagnoses are provided to users.

2. **Companion and social assistance.** The robot accompanies the user through voice interactions and handshakes. Through the camera and microphone, communication assistance is also provided to users to achieve stable communication.

3. **Entertainment assistance.** The robot can play music, games, and videos to awaken the user's memories. Specially selected or developed games may provide targeted and specific treatments.

4. **Health care assistance.** The robot needs to be equipped with services such as wake-up calls, meal reminders, medication reminders, grasp important items, and record the location of frequently used items when necessary. It should also be capable of monitoring the user's physical and physiological characteristics and be able to remind the caregiver when the user falls.

5. **Rehabilitation assistance.** The robot has dual arms to provide users with exercise guidance. The exercise intensity can be adjusted dynamically according to the user's needs.

CHALLENGES AND PROSPECTS

Robots are indifferent and emotionless, but we hope that robots can be full of humanistic care. Therefore, we surveyed and summarized the design and applications of robots for people with dementia that follow the principles of PU and PEOU. The human-oriented design encourages users to be willing to use this product, and the applications can cover the needs of people with dementia to achieve ease of use. And the user should feel comfortable and safe when interacting directly with the robot. Specifically, robots can take heavier responsibility in the treatment of dementia, and in the care and rehabilitation of patients. Correspondingly, we will develop further functions based on the MOBI robot.

There are three main challenges in the development of robots for people with dementia. From an economic perspective, the cost of the robot itself is relatively high, and the cost of maintenance must be calculated. From the technical aspect, the problems include the treatment effect is difficult to quantify, the robot hardware is unstable, and the software is vulnerable to attacks. These robots cannot cover all the problems that may occur in the real world. From the moral aspect, the dignity, safety, and privacy of people with dementia need to be considered. In summary, robots can have future development prospects only if their performance, cost, ethics, and safety are ensured at the same time.

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失智症機器人的技術與應用發展概況

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摘 要

由於人口老齡化和2019年新型冠狀病毒的影響，醫療和長期護理設施發生了巨大變化，老年失智症患者的病情變得危急。他們缺乏足夠的治療、陪伴和照顧。這項研究探討了機器人的發展如何幫助癡呆症患者。它處於一個包括傳感、決策和結構

組件的架構之下。本文回顧了滿足失智症患者需求的方法，並總結了相關機器人技術的應用，包括診斷、治療、醫療保健和康復的輔助。並提出了一種配備多種應用的智能輪式機器人系統，為失智症患者提供全面的服務，並致力於維持其日常生活活動。本研究的結果和討論被提出以幫助相關領域的工程師和臨床醫生設計和使用用於失智症機器人。