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The Current Status and Future Development of Elderly Care Robot Technology

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Abstract:

The increasing ageing of the world population is reforming the demographics and the classical paradigms on elder care have been caught in the crossfire of lack of professional care providers, high care load, and failure to provide good care. Robot technology of elderly care has therefore become a major point of direction to crack out of this dilemma. The paper provides a systematic review of literature and case analysis of the situation and future of the elderly care robot technology. The structural design, based on safety and adaptability, at the technical foundation level is realized through 3D printing as it provides lightweight and customization, as well as through soft actuators that improve the safety of the interaction. Sensor technology goes beyond the single-perception barrier of sensor technology through multi-modal fusion, and non-intrusive health monitoring is possible through flexible tactile sensors. Artificial intelligence enables robots to plan autonomous motion, and bionic neural networks and fuzzy logic codes control the avoidance of obstacles and positioning in moving environments optimally. The application in practice, robots have proved useful in everyday care, health control, and emotional companionship, which might lead to the better life of older people and relieve the burden on the care. Meanwhile, current technologies face challenges including insufficient flexibility and environmental adaptability, high R&D and maintenance costs, low social acceptance, safety risks, and a disconnect between technology and needs. Three areas, namely, technology, design, and ecology should be developed in the future. As the essence is that technology empowers humanity, it strives to support the development of a sustainable elderly care system and fulfill the vision of dignified home-based aging of the aged.

Keywords: Elderly care robots; technical foundations; development challenges; aging society.

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1. Introduction

The population of the global aging is modifying the demographic structure of the world with a significant influence on the social economy, the provision of services to the population, and families. It was revealed that the population of individuals over the age of 65 is at the present high level of 703 million, and the number is expected to grow to 1.5 billion by 2050 [1]. Besides, a survey conducted by the Population Division of the United Nations Department of Economic and Social Affairs (DESA) has projected that by that time, one in every six planetary populace will be aged above 65 years [2]. Medical systems, care providers and families have been devastated by this change and therefore development of sustainable elderly care model has been a fundamental issue. The old model of elderly care is based on human resources and is caught up in dilemmas. There is a lack of professional caregivers in the world market - under the impact of working hard, low wages, and a low level of development, the labor force is not readily available. Besides this, the physical and mental health of the caregivers is also vulnerable in the course of work: formal caregivers experience long-term fatigue, and informal family caregivers do not possess professional knowledge and are likely to feel negative emotions. All this makes one question the viability of the conventional model.

It is against this background that robotic technology has brought a breakthrough in regard to the innovation of the elderly care models. The assistive robots and general medical service robots may provide useful assistance that does not only contribute to better quality of life of the elderly, but also helps them in enhancing their cognitive and physical well-being [3]. Some of the situations that the elderly care robots can address include those involving day-to-day care, health management, mental support, and emotional support. As an example, robot systems with sensors and actuators may give the elderly physical help in issues such as supporting mobility, being a personal hygiene care, and also doing household tasks. With preset programs customization, these robots will be able to fit the needs of various older adults precisely, which will demonstrate personalized and timely support in the form of responsiveness. The elderly can be given emotional support and cognitive stimulation by social robots since these robots are known to engage in conversations with them, play games with them, and even help them in carrying out reminiscence therapy (which can help improve the overall quality of life of the elderly) [4]. Robots can operate twenty-four hours compared to the human resources whose operations are also precise and efficiently compensate the lack of human resources.

Nevertheless, there are still issues of introducing robots into care scenarios in many respects. In the first place, there is the weakness of robots with respect to adaptability and flexibility, the majority of existing robots are capable of only doing what was programmed in them and cannot react to unforeseen scenarios. Moreover, robots can be potentially dangerous in terms of collisions and malfunctions in physical contacts; it is especially dangerous to frail elderly people. Meanwhile, the difference between needs and technology is still observed: components of certain robots are complicated to use, also, the style of their design is not correlated to the daily rituals of the elderly members, and that is why elderly people cannot use these devices as professionals. Consequently, the purpose of this review is to consider the position of elderly care robot technology, discuss technical principles of this technology in three domains structural design, sensor technology, and AI algorithms and demonstrate the examples of the existing types and benefits of elderly care robots. In the meantime, it defines constraints and future trends. Owning to the arrangement of literature, Empirical studies, and cases, this review will offer allusions to the sustainable development of this area in aspects of technological development, cost management, moral standards, and demand format. It is hoped to drive future research and development, policy making, and industrial practice, advance robots to service the ageing society and lead to building an inclusive care system.

2. Technical Foundations of Elderly Care Robot

2.1 Structural Design

The structural design of elderly care robots takes safety and adaptability as the core, focusing on the application of lightweight materials and the development of flexible actuators. It aims to meet the care scenarios where the elderly have fragile physical conditions and diverse needs, make up for the lack of flexibility in traditional human care, and at the same time adapt to the usage requirements of complex spaces such as families and nursing homes.

3D printing technology is a dual-key support for achieving lightweight and customized robot structures. To achieve the goal of structural lightweighting, lightweight materials can be selected from a macro perspective, with common ones including titanium alloys, aluminum alloys, magnesium alloys, ceramics, plastics, as well as glass fiber and carbon fiber composite materials. Secondly, lightweighting can also be realized through optimized structural design. The main methods adopted include: constructing hollow

sandwich and thin-walled stiffened structures, building hollow lattice structures, and conducting integrated structural design and special-shaped topology optimization design [5]. More importantly, 3D printing is a technology with a higher degree of "design freedom". It enables designers and engineers to create unique products, and even when these products are produced in small batches, the optimization of cost-effectiveness can still be achieved [6]. This fulfills the customization needs of elderly care robots, facilitating the design of care robots that match the specific requirements of different service recipients. The core advantages of lightweighting and customization lie in reducing the overall weight of the equipment while retaining sufficient supporting strength, avoiding operational inconvenience or collision risks caused by heavy equipment, and adapting to high-frequency care needs of the elderly such as daily mobility assistance and eating assistance.

For example, a research team from Harvard University has developed a flexible robotic glove specifically designed for the integration of auxiliary therapy and home rehabilitation scenarios. The core component of this glove is a soft actuator with a molded elastomer cavity—by pressurizing the fluid inside, the soft actuator can drive the glove to perform preset movements. In terms of the manufacturing process, 3D printing technology is used to produce the elastomer mold, and then the overall assembly is completed in multiple stages; leveraging the precision of 3D printing, the robotic glove can be customized to fully match the actual hand size and shape of patients according to their specific needs. For people with motor function impairments, this flexible robotic glove can provide targeted physical therapy training to help them gradually restore hand movement capabilities [7]. Yong-Lae Park et al. proposed a soft robotic sensing unit for human gait measurement. Its soft sensors, electronic components, and assembly molds are all fabricated using integrated 3D printing technology. It features full-process 3D printing integration and high measurement accuracy. It can be flexibly adapted to different joint measurement requirements through 3D printing and quickly achieve design iterations, ultimately enabling precise collection of gait data. [8]

This technical feature is deeply in line with the demands of the nursing scenario: the lightweight design reduces the risk of impact on the elderly, catering to their fragile physical condition and avoiding injuries caused by improper force or fatigue in traditional manual care. Customization can design dedicated components based on the physical differences of the elderly, meeting diverse needs and solving the limitation of "one-size-fits-all" in manual care. At the same time, the lightweight design enhances operational flexibility, making up for the shortcomings of manual assistance in multiple body positions and complex environments. The modular and miniaturized structure of customization can also fit into the gaps between household furniture and narrow passages in nursing homes, ensuring the efficient implementation of care.

As the core component for robots to perform nursing actions, the development of soft actuators has broken through the limitations of traditional rigid actuators. Traditional rigid actuators are heavy, occupy a large volume in the robot structure, are not efficient and stable enough, and have poor safety. They cannot precisely meet the various needs of nursing robots. Soft actuators are safer and can prevent hard joints from causing harm to the elderly. More research is focusing on soft actuators, aiming to fully optimize the shortcomings of traditional rigid actuators and create safer, more reliable, lighter, smaller and more flexible soft drives to meet the higher demands of robots. For instance, Duduta et al. proposed a crawling flexible robot. Its driving component adopts DEA (dielectric elastomer actuator) and is fabricated through multi-layer manufacturing technology, which can be formed without pre-stretching. It features high flexibility, high energy density, and high strain. At the same time, it has self-sensing characteristics and precise simulation models, and its performance can rival that of biological muscles. It can reduce or avoid the reliance on rigid components and adapt to the requirements of flexible movement [9]. Researchers have developed a Finite Element Analysis (FEA)-type soft actuator. Designed for adaptive applications across different scenarios in the fields of medical and industrial robotics, this actuator exhibits high scenario adaptability, inherent compliance, and adjustable stiffness. It also possesses reverse drive capability and off-axis deformation capacity, which enhance the safety of human-robot interaction. It can serve as a preferred solution in scenarios with specific requirements and supports the adjustment of performance parameters to meet needs based on application scenarios [10]. Lei Bing and his team have developed an intelligent soft robot equipped with LCE-based soft actuators. The core actuating component of this robot adopts a liquid crystal elastomer (LCEs) structure and is designed with a photo-driven mechanism. It features liquid crystal anisotropy and rubber-like soft elasticity, along with strong remote-control capability, rapid response time, and an efficient mechanism for energy accumulation and release. Under external environmental stimuli, it can achieve reversible complex shape changes and movements. Additionally, it allows for the adjustment of actuator parameters according to application scenarios and the rapid optimization of performance [11].

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2.2 Sensor Technology for Elderly Care Robots

Sensor technology serves as the core foundation for elderly care robots to achieve environmental perception, safe interaction, and health monitoring, and exerts a profound impact on the quality of robotic services. In complex scenarios such as homes and nursing homes, sensors are like the "eyes", "ears", and "tactile nerves" of robots: they support robots in accurately identifying furniture layouts and dynamic obstacles to achieve safe obstacle avoidance; ensure robots can perceive contact force during actions such as assisting the elderly to stand (or "supporting the elderly") and feeding them, so as to avoid harming the elderly; and through methods like non-contact monitoring, capture the elderly's vital signs and risky behaviors without their awareness. Therefore, the maturity and performance of sensor technology directly determine the accuracy and reliability of robotic care services and are the key to whether robots can truly become trustworthy "intelligent companions" for the elderly.

However, due to the inherent defects of a single sensor, such as "insufficient information collection and weak robustness", relying solely on a single sensor to perceive the workspace of a nursing robot is difficult to meet the practical needs of the nursing robot. To break through this limitation, multi-sensor information fusion technology has received extensive attention from the academic community and has been proven to be an effective means to enhance the environmental perception performance of robots. In the current technical system, the mainstream sensor fusion solutions can be clearly divided into two categories: one focuses on "the fusion of visual and inertial navigation", optimizing the perception effect through the complementary data of the two; The second approach focuses on the "fusion of laser and vision", relying on the combined advantages of the two types of sensors to enhance the accuracy of environmental cognition [12]. Kim et al. developed a compact multi-functional flexible sensor. Its core sensing part adopts a structure that integrates three heterogeneous sensing mechanisms: optical sensing, microfluidic sensing, and piezoresistive sensing, and is made of flexible materials. It has the characteristics of being capable of detecting single deformation modes such as tension, bending and compression, decoupling superimposed deformation modes, and having great application potential in the field of human-computer interaction [13].

In terms of sensor materials, especially for elderly care robots, the application of tactile sensors is increasingly advancing. Traditional rigid tactile sensors have gradually been replaced by flexible tactile sensors, which can better conform to irregular contact surfaces and provide more accurate measurements. For example, Wajahat et al. proposed a design scheme that integrates piezoresistive flexible force-tactile sensors into a glove carrier. By printing the sensors on the surface of the glove, this scheme enables accurate capture of finger movement trajectories and perception of human movement states, while also realizing remote control of robotic equipment. This technology provides a practical tool for the rehabilitation treatment of patients with hemiplegia: it not only facilitates real-time monitoring of the patients' movement data during rehabilitation training but also helps patients complete daily activities through remotely controlling robots, thus contributing to the rehabilitation process [14]. Lin et al. fabricated a large-area self-powered smart bed sheet, which is equipped with a triboelectric sensor. Continuous monitoring of sleep posture can be achieved through the electrical energy output by the sensor, and the sleep quality can be evaluated based on the user's sleep posture, wake-up frequency and other data. In addition, this intelligent bed sheet system also features an out-of-bed alarm function, opening a new path for the field of non-invasive sleep monitoring [15].

2.3 Artificial Intelligence Technology

The key to the present-day care robots is artificial intelligence (AI), allowing them to learn through the user behavior, adjust their actions on the needs of individuals, and take their own decisions. The AI algorithms, in particular, have been applied to maximize the mobility of robots. Although the family living room and the nursing home corridor, as well as the hospital ward, are complex and dynamically changing environments, in elderly care scenarios, robots must be able to move across them. Not only should they be able to pass not hitting objects such as the elderly and furniture but also to the point of the care (ex: beside the bed of an elderly, next to the dining table). This entire gamut of mobility requirements has technical support in the form of AI algorithms. Today's robots are no longer content with the simple path planning of „from A to B" but rather pursue autonomous motion planning for robots. Motion planning pays more attention to the interaction scenarios of robots in dynamic environments and is committed to generating motion trajectories that match the environment within the workspace. This indicates that when a robot moves towards a target point, motion planning not only needs to plan the moving route but also must comprehensively analyze multiple key factors: the kinematic characteristics of the robot itself (including the range of motion of joints and motion constraints), real-time speed and attitude, as well as the state changes of surrounding dynamic objects (such as pedestrians and other robots) [16]. This kind of motion planning is

particularly important in care robots, as it can effectively avoid collisions with service recipients or surrounding obstacles, thereby greatly enhancing safety. With the continuous development of AI algorithms, new algorithms such as bionic neural networks have been applied in the field of robotics. Unlike traditional algorithms, bionic neural network algorithms do not rely on the traditional training process. Instead, they automatically calculate the dynamic activation value function of each neuron through the information transmission between neurons. Based on the real-time solution of the dynamic activation potential function of neurons, a feasible path extending from the initial position to the target position along the direction of increasing potential values can be obtained. This path is the planned path [17]. In addition, fuzzy logic algorithms have also been widely applied in the path planning of mobile robots. Li et al. proposed an improved fuzzy control method for local path planning and conducted targeted research on strategies to solve problems in the planning process: first, they integrated two behaviors—obstacle avoidance and wall-following—into the fuzzy controller, and realized the flexible alternation of these behaviors through internal rules; second, to address the deadlock problem caused by multiple U-shaped obstacles in fuzzy control, they designed a cumulative angle sum judgment method to help the robot escape from deadlock; finally, by adding a trap prediction mechanism, the robot can break through the limitations of the sensor measurement range to a certain extent, predict the feasibility of the forward path and make timely decisions, thereby reducing the generation of redundant road sections [18]. Owing to its good real-time performance and strong ability to resist external environmental interference, fuzzy logic exhibits significant adaptability in path planning tasks.

3. Applications and Advantages of Elderly Care Robot

3.1 Daily Care

Daily care is the most fundamental and widely applied scenario for elderly care robots, mainly focusing on the two core issues of diet and movement that the elderly face in their independent lives. By integrating mechanical structures with intelligent control, care robots can provide safe and efficient physical assistance, reducing the elderly‘s reliance on care from others. In daily care, the significance of dietary care is self-evident. With the intensification of the aging problem, the shortage of nursing resources has directly affected their quality. Nursing staff often face the situation of overwork. Not only are they unable to communicate and interact fully with the care recipients, but they also find it difficult to ensure meticulous care during the dietary process, such as controlling the eating speed and adapting the food form. The application of meal assistance robots has effectively broken through this limitation, especially when helping the elderly with weak constitutions or disabilities, becoming a key tool for ensuring food safety and enhancing the care experience. For instance, Yang Zhidong and others focused on the autonomous eating needs of people with armless disabilities and designed an intelligent auxiliary embedded system. The system collects facial images through CCD cameras, determines the mouth position with the binarization processing of FPGA and the image analysis technology of Nios II, and then generates a continuous PWM wave by FPGA to control the movement of the robotic arm to deliver beverages. The system also integrates a voice recognition module, enabling full-process human-computer interaction. It also features auxiliary functions such as automatic beverage addition and abnormal water temperature alarm [19].

In terms of mobility assistance, for elderly people with insufficient physical strength and poor balance, it is necessary for caregivers to carry them in and out of bed and do other activities. This poses a great challenge to the strength of caregivers. The emergence of transportation robots not only reduces the transportation burden on caregivers, saves time, but also lowers the risk of secondary injuries to the elderly during the transportation process. Improve the quality of family care for the elderly. For instance, the Herb robot developed by Carnegie Mellon University in the United States, by integrating sensors and non-visual signal detection devices, can accurately identify the shape of surrounding objects and perceive environmental features. Relying on this technological advantage, the device can effectively perform the functions of transporting and transferring for the elderly [20]. In addition, the Robear robot, developed by the Riken Institute of Japan, is specifically designed for elderly people with mobility issues and can perform the core function of „picking up the elderly from the bed and assisting in their movement“. In terms of design, Robear focuses on the dual goals of „safety and comfort“: its surface is wrapped with organic materials to prevent hard components from coming into direct contact with the elderly‘s body. The sensors equipped on the robotic arms and the body endow it with high-precision tactile perception capabilities. It can quickly collect the weight data of the elderly through touch and adjust the transportation parameters accordingly to ensure a smooth and safe transfer process, while also providing the elderly with a good body-sensing experience [21].

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3.2 Health Monitoring

One of the value-added scenarios of elderly care robots is health monitoring. It uses the technology of multi-sensor fusion and data analysis through AI to solve the paradigm of health management of the traditional model of routine physical examination + passive medical treatment, offering the opportunity to provide an all-day non-invasive monitoring of the vital indicators and daily activity of the elderly. It promotes interventions in the health domain through a risk early warning system, and it is especially adequate in the fundamental elderly health requirements like chronic illness management and fall prevention. Fall prevention and emergency rescue are the most vital in health monitoring cases. Nonetheless, most caregivers often find it hard to determine the risk of falling among the elderly using their external conditions alone and once the elderly fall, it is often the difficulty to arrive in time to save their lives. So, it is especially significant that fall prevention robots are introduced. Here, an example would be the care robot system Hobbit which is specifically tailored to the use of the elderly demographic suggests that its fundamental functional tasks must be the prevention and management of any possible fall risks, as well as the management of the emergencies. Regarding hardware implementation, the system consists of two main parts (a robotic platform with a 5-degree-of-freedom (DOF) robotic arm, and a multi-functional gripper) [22] which is placed on a robotic platform to allow the system to execute different refined work such as different suppression of objects of various shapes and forms, which act as a practical support to enforce different care situations.

The elderly population faces the problem of chronic diseases. As a result of such diseases, patients tend to fall into physical disintegration and mobility restrictions such that they are unable to practice daily tasks without the support of caregivers and thus they will be compelled to depend on their assistance long-term. Given that chronic diseases have become the key concern to the health of the elderly population, improving the home monitoring of elderly patients with chronic illnesses and monitoring their health dynamics in a timely manner is vital to prevent the further development of diseases and enhance the effectiveness of health management. The smart medicine box robot introduced by the research group of the Hangzhou Dianzi University is specially applied to the situation of reminding the elderly of taking medicine. Its smart system consists of a remote server end and an intelligent medicine box end. It also can remind the elderly to take medication but at the same time, it capabilities the ability to capture key data including the time and dosage of medication, standardizing the management of the medication process [23]. The problem of missed medication documentation and wrong dosages that take effect on the old-aged are very specific to this smart medicine box robot. It also has a two-terminal design, which provides the traceability of medication information, as well as allowing remote visualization by children, which is more than convenient in case of the autonomous living of seniors. Its light design ensures that it is less expensive and has lower operating requirements due to which, it can be easily incorporated into daily family affairs and marketed. If the dialect voice interaction is further streamlined to suit the habit of the elderly, then its flexibility can be further enhanced. In the meantime, the automatically gathered data on the medications taken by the elderly can help the primary care doctors make sense of how well the elderly take medications and revise their medication regimen, making it easier to implement the family medication management process and the primary care. In addition, The intelligent medicine box developed by researchers from Chongqing University of Technology has a unique information sharing function. With the help of the GSM system, it can push the medication information of the elderly to the mobile phones of their guardians in real time, allowing guardians to promptly understand the medication situation of the elderly even when they are not around [24]. This design precisely addresses the challenge of medication supervision for elderly people living alone, and is particularly suitable for remote care scenarios, avoiding the problem of missing or wrong doses without anyone knowing. Moreover, GSM technology is mature and has a wide coverage. It can be stably used even in areas with weak networks, lowering the threshold for use. If abnormal medication warnings are added in the future, a more comprehensive medication guarantee can be formed.

3.3 Emotional Companionship

As the process of aging of the population has grown faster, the emotional loneliness of elderly people, as well as addressing their spiritual needs, have made it essential in the older generation of the system of elderly care. Not only the temporal and spatial nature of family companionship, but also the deficiency of the community care services coverage and the absence of the personalized needs are the root causes of the circumstances. The need to innovate with emotional companionship robots as the messenger of technology-mediated elderly care is based on the human-computer interaction technology to funnel simulation of social activity to create a system of service, which combines emotional warmth and social affiliation. They have taken the significant role of being an addition to the conventional family companionship and community

care as a means of providing a technical way out of the spiritual nexus problem of the aging population. From the perspective of the emotional comfort function, its core lies in building a deep emotional connection through „personified interaction design“ rather than a simple functional response. This type of robot is usually based on a form that fits the emotional cognition of the elderly and combines natural language processing and emotion recognition technology to achieve an upgrade from „passive dialogue“ to „active empathy“. On the one hand, by capturing the emotional fluctuations in the tone of the elderly through voice recognition and combining with empathy algorithms to generate targeted responses, mechanical comfort can be avoided. On the other hand, by relying on user profiling technology to store the life preferences and emotional memories of the elderly, and actively evoke emotional resonance in interaction, the elderly can feel „understood“ and „valued“. For instance, the seal-shaped emotional support robot Paro, which is specially designed for therapeutic scenarios, has been meticulously crafted in terms of emotional interaction and form restoration. Users can gradually establish an emotional connection with the robot by getting familiar with its name and exploring its behavioral functions. This not only prevents users from losing interest but also subtly develops a fondness for Paro. In addition, the R&D team also conducted a special investigation into the ecological habits of harp seal pups, all for the purpose of restoring their lively and cute appearance. At the same time, the calls of real seal pups are collected and put into the robot to make Paro‘s appearance and voice more realistic, and to make the interaction more intimate [25]. Intuition Robotics has launched a social companion robot named Eli.Q, which features simple communication and intuitive operation, making it very suitable for the elderly to use. When the elderly chat with Eli. Q in their daily lives, they will naturally tell them about their own situations. After collecting this information, Eli. Q will process it with the help of AI and big data analysis technologies. It can not only clearly understand the preferences, living habits and personality traits of the elderly, but also recommend suitable activities for them based on these personal circumstances [26].

At the level of social connection, the core role of emotional companionship robots is to break down the „barriers of time and space“ and build a diverse social network of „elderly - family - community“. For elderly people living alone, the operational threshold of smart devices is the main obstacle to their integration into digital social interaction. Robots, through designs such as voice control and simplified interaction processes, reduce the operational difficulty of video calls and information reception, essentially solving the social isolation caused by the „digital divide“. At the community level, robots play the role of „social media“, connecting scattered elderly people by organizing interactive collective activities to form social groups based on common interests, helping the elderly rebuild a sense of community belonging and avoid „social marginalization“ caused by living alone. In addition, robots can also serve as „information hubs“, feeding back the emotional states and cognitive conditions of the elderly to their families and community workers, providing data support for subsequent precise care, and achieving the synergy of „technological connection“ and „humanistic care“.

4. Conclusion

The present review concentrates on the evolution of elderly care robots in the issue of aging of the population across the world. It initially explains the dilemmas of conventional care models by aging, including inadequacy of professional caregivers, family pressure too much on them, and difficulty in quality of services provided. Then, it indicates that robot technology is the most important way to avoid this dilemma. The review studies the technical foundation level through three dimensions, i.e., structural design, sensor technology, and artificial intelligence. The structural design focuses on safety and flexibility, lightweighting and customization was implemented with the help of 3D printing technology. The soft actuators are used instead of rigid actuators to improve the safety of interaction. Multi-modal fusion provided by sensor technology overcomes the limitations of single perception, and contactless health monitoring is accomplished by flexible tactile sensors. Robots have autonomy in planning motion persistently, which is enabled by artificial intelligence and the algorithms of bionic neural networks and fuzzy logic streamline obstacle avoidance and robot positioning in their dynamic surroundings. Regarding application cases, it has been proven that robots have a working value in everyday care, in the health service and in companionship during emotional support: in everyday care, robots used to help elderly citizens eat on their own address the issue of secondary injuries, as well as in transportation, robots are able to mitigate the threat of secondary injuries during the transportation process. Risk early warning is foreseen in time and standardized medication management is attained in the health monitoring area with the help of the fall prevention robots and intelligent medicine boxes. As per emotional companionship, robots provide psychological comfort due to being anthropomorphically designed in terms of interaction design, thereby destroying the barrier of time and space so that the elderly can be connected to their families and communities to reduce social isolation.

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The current development of elderly care robots still faces multiple challenges. From a technical perspective, robots lack flexibility and environmental adaptability. Most of them can only perform pre-programmed tasks and are difficult to handle unstructured and unexpected scenarios in the home. The high R&D and maintenance costs limit the application of high-quality materials, making it unaffordable for ordinary families. At the social level, some elderly people have a sense of distrust towards robots due to their complex operations and privacy concerns, and ethical controversies such as data security and deteriorating interpersonal relationships have not yet been resolved. In terms of safety, hardware malfunctions and software misjudgments may cause harm to the elderly, such as sensor failure leading to obstacle avoidance errors. The existing testing standards and redundant designs still need to be improved. In addition, there is a gap between technology and demand. Some robots are designed not in line with the usage habits of the elderly, and the operation threshold is relatively high.

In the future, elderly care robots need to be advanced from three aspects: technology, design and ecology. Technically, more adaptable core components should be developed, integrating softer bionic materials with high-precision sensors to enhance safety. Leverage 5G and edge computing to achieve multi-robot collaboration and integrate it into the smart home ecosystem to provide full-process services. At the design level, it is necessary to deeply involve the elderly and caregivers, simplify the operation interface, optimize dialect voice interaction, and lower the usage threshold. In terms of ecological construction, it is necessary to establish data security norms and ethical standards and clearly define the positioning of robots as "supplementing rather than replacing" human care. Enhance social acceptance through popular science and pilot applications, and at the same time promote the integration of robots with primary medical care and community services to form a comprehensive elderly care support system.

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