The Application Status and Technological Progress of Service Robots in Home Automation

Kangming He*

Pittsburgh Institude, Sichuan University, Chengdu, China

*Corresponding author: 2021141520020@stu.scu.edu.cn

Abstract. This paper examines the application status and technological progress of service robots in home automation, with a particular focus on floor cleaning robots and companion robots for Alzheimer's patients. The evolution of service robots has been driven by advancements in artificial intelligence, sensor technology, and autonomous navigation, transforming them into indispensable tools in modern households. Floor cleaning robots, equipped with advanced sensors and efficient algorithms, have revolutionized routine household chores by autonomously maintaining clean floors. Companion robots, such as Pepper and those developed in projects like RAMCIP, have shown promise in assisting Alzheimer's patients, offering both practical and therapeutic support. The article also delves into the key technologies enabling these robots, including sensor systems, obstacle avoidance algorithms, and human-computer interaction. Despite the significant progress, challenges remain, particularly in optimizing obstacle avoidance, enhancing HCI, and addressing ethical concerns in caregiving roles. The article concludes by highlighting the future potential of service robots to further integrate into smart homes, offering personalized and context-aware solutions to meet the unique needs of individual households.

Keywords: Service robot, Floor cleaning robot, Human-computer interaction.

1. Introduction

Service robot is a kind of advanced, intelligent, and programmable system designed to assist humans in various aspects of daily life and work. These robots are increasingly becoming an integral part of modern society, functioning as tools that not only offer convenience but also significantly enhance human productivity and overall quality of life [1]. In today's classification of service robots, they are generally categorized into two main types: personal robots and domestic robots [2]. Personal robots are designed for individual use, often tailored to specific activities or tasks that enhance personal experiences or learning. This category includes toy robots [3] and educational robots [4]. On the other hand, domestic robots are designed to operate within the home environment, taking on tasks that would otherwise require significant time and effort from the household members. Examples of domestic robots include floor-cleaning robots and window-cleaning robots [2]. These robots exemplify the practical applications of robotics in everyday life, offering solutions that simplify chores and allow individuals to focus on other activities that matter to them. As service robots continue to evolve, their role in both personal and domestic settings is expected to grow, driving further innovation and making them indispensable tools in modern life [2]. As artificial intelligence, sensor technology, and autonomous navigation and positioning technologies advanced, robotics gradually matured. The aging population, changes in family structure, and the busy modern lifestyle [5, 6, 7] have driven the increasing demand for smart home and automation solutions. In this context, addressing the challenges of an aging population has become a global, coordinated, and ongoing effort crucial for ensuring sustainable development in the long term [8]. Several technological advancements have enabled the widespread application of robots in the home environment, including sensor techniques, obstacle avoidance algorithm, and human-computer interaction [9]. Ultrasonic sensors, Light Detection and Ranging (LiDAR) sensors, and vision cameras are the most widely used sensors in modern service robot. Because of their virus working principles, they have different advantages in different working environments [10, 11]. With the advancement of computer technology, the obstacle avoidance algorithm is continuous iterating. A three-dimensional obstacle avoidance control design based on an integrated Particle Swarm Optimization (PSO) algorithm and a robot manipulator obstacle avoidance algorithm grounded in decision-making power are advanced recently [12]. Visual sensors and auditory sensors are the basic of Human-Computer Interaction (HCI), then service robots can analysis the data selected by these sensors and response to what human needs [13]. This article will explore the development background and current status of various service robots in home automation, with a particular focus on floor cleaning robots and companion robots for Alzheimer's patients, and will provide predictions for the future development of home service robots.

2. Application atatus of service robots

2.1. Floor Cleaning Robot

One of the most well-known and widely adopted applications of home service robots is the floor cleaning robot. These robots have gained immense popularity for their ability to autonomously handle one of the most tedious and often disliked household chores: floor cleaning. Traditionally, floor cleaning, whether it involves sweeping or vacuuming, has been a time-consuming and repetitive task that many people find boring and unpleasant. Floor cleaning robots provide a convenient solution by handling this task, enabling homeowners to maintain clean floors without having to do the work manually. [14].

Equipped with advanced sensors, mapping technology, and efficient cleaning algorithms, these robots can navigate around furniture, avoid obstacles, and thoroughly clean various types of flooring surfaces. Many models are also designed to return to their charging stations automatically when their battery is low, ensuring that they are always ready for the next cleaning cycle. As a result, robots not only save time and effort but also contribute to maintaining a cleaner home environment with minimal human intervention. The widespread adoption of these robots highlights the growing trend of integrating automation into everyday household tasks, making life more convenient and freeing up time for more enjoyable activities [9, 14].

Nowadays, a complete Floor cleaning robot can be divided into moving system, cleaning system, perception system and controlling system [14]. Mobile mechanisms generally use wheeled mechanisms, and three wheels structure are widely used because of its flexibility and stability [15]. The cleaning system is designed with two large edge sweeping wheels, which can make corners and floors more thoroughly and cleanly swept. The relative rotation of the two sweeping wheels prevents garbage from slipping off the bottom of the machine, making cleaning more complete. At the same time, the dual function of cleaning and vacuuming ensures that the dust swept up enters the garbage collection box in a more regular and smooth manner. At the same time, a mop is placed at the rear end of the robotic floor cleaner to clean the floor after being swept by the sweeping wheel and vacuum cleaner [14]. For the perception system, by installing photoelectric sensors in the power box of the front wheel and cleaning wheel, the robot can have the function of automatically preventing the body from getting stuck and the cleaning wheel from getting stuck. When it gets stuck, it will automatically retreat or shut down. An infrared reflection detector is also installed on the collision head, which can automatically determine whether there is a cliff ahead and avoid it automatically [16, 17, 18]. The control and working environment of robotic floor cleaners are often uncertain or variable, so it is necessary to balance safety, reliability, anti-interference, and cleanliness. Detecting the environment with sensors, analyzing signals, and understanding the environment through appropriate modeling methods are of particular significance [10]. Research on intelligent robots has shown that for autonomous mobile robots working in complex unstructured environments, further improvement in their automation level mainly relies on pattern recognition and obstacle recognition, real-time data transmission, and appropriate artificial intelligence methods. It is also necessary to further develop global models to obtain global information for robots [12, 19].

2.2. Companion Robots for Alzheimer’s Patients

One significant application of home service robots is their ability to assist patients suffering from Alzheimer's disease. Alzheimer's disease is a progressive neurodegenerative disorder that is recognized as one of the most prevalent forms of dementia. Patients diagnosed with this condition often face a range of challenges, including severe memory loss, cognitive impairment, difficulties with language and communication, as well as noticeable changes in behavior and personality [20]. As the disease progresses, these symptoms worsen, making it increasingly difficult for patients to manage daily tasks and maintain their independence.

In response to these challenges, advancements in service robot technology, coupled with a deepening understanding of Alzheimer's by caregivers, have paved the way for robots to take on many of the caregiving tasks traditionally performed by human caregivers. These robots are now capable of assisting with various critical activities, such as reminding patients to turn off appliances like stoves or lights, helping them adhere to their medication schedules, and ensuring that they take the correct dosage of their prescribed medicines [21].

Research conducted by the Vienna University of Technology provides a valuable example of service robot technology and experience in the home environment [22]. The study introduces a service robot named Hobbit, designed to offer social companionship and household assistance to humans. Equipped with LiDAR sensors and vision cameras, Hobbit can perform tasks such as map building, self-localization, and safe navigation. Additionally, the robot's arms were specifically designed for these purposes [23]. For HCI, the robot utilizes a Microsoft Kinect camera to detect users and accept gestures as an input modality. While performing tasks, the HCI system processes human gesture commands, enabling the robot to assist with retrieving necessary items using its arms. The robot's obstacle avoidance algorithm ensures safe movement within the home, allowing it to complete its service tasks effectively [22].

The potential of service robots extends beyond just physical assistance. Many researchers and engineers are exploring how these robots can play a therapeutic role in the lives of Alzheimer's patients. For instance, Pepper, a humanoid robot developed by SoftBank Robotics [24], has been integrated into the care routines of Alzheimer's patients. Pepper is designed with the capability to engage in personalized conversations, providing not just companionship, but also emotional support. By stimulating cognitive functions through interactive dialogue and encouraging communication, Pepper can help mitigate some of the cognitive decline associated with the disease. The integration of Pepper robots into the daily care of Alzheimer's patients is seen as a promising development, with substantial potential to enhance the quality of life for these individuals [25].

Additionally, the Robotic Assistant for MCI Patients at home (RAMCIP) project represents another innovative approach to using home service robots for Alzheimer's care. This project focuses on developing robots specifically designed to assist with daily living activities, providing a form of caregiving that enables Alzheimer's patients to remain in their homes for as long as possible while receiving the support they need [26]. The feedback from the Alzheimer's community has been largely positive. A survey conducted by the Barcelona Alzheimer's Treatment and Research Center revealed that a majority of Alzheimer's patients and their caregivers view service robots favorably, recognizing their potential to ease the burden of care and improve the overall well-being of patients [21]. This growing acceptance and utilization of service robots in Alzheimer's care highlight the potential of these technologies to transform the caregiving landscape.

3. Key Technologies

Although various service robots in home have different specific functions and service targets, their working environments are same, so most of them have same key technologies.

3.1. Sensor

In the operation of home service robots, having a comprehensive understanding of the surrounding environment is essential for effective and safe performance. These robots rely on various types of sensors to perceive and interpret their surroundings, which enables them to navigate, interact with objects, and perform tasks autonomously. Floor cleaning robots and companion robots for Alzheimer's patients both navigate within the home, making sensors a crucial technology as they provide essential environmental data to the service robots [14]. The primary technologies employed by these robots to gather environmental data include ultrasonic sensors, Light Detection and Ranging (LiDAR) sensors, and vision cameras [10, 11].

Ultrasonic sensors are often used for basic distance measurements and obstacle detection. These sensors emit sound waves and measure the time it takes for the echo to return, which helps the robot determine the proximity of objects in its vicinity. While ultrasonic sensors are cost-effective and reliable for short-range detection, their resolution and accuracy can be limited in more complex environments [16, 17].

LiDAR sensors, on the other hand, provide a more detailed and accurate representation of the environment. LiDAR works by emitting laser beams and measuring the time it takes for the light to bounce back after hitting an object. This allows the robot to create a precise 3D map of its surroundings, which is particularly useful in complex environments where accurate spatial awareness is crucial. LiDAR is highly valued for its ability to detect and map objects over long distances with high precision, making it an ideal choice for advanced navigation and obstacle avoidance tasks [18, 27].

Vision cameras serve as another critical tool for environmental perception, capturing images and video that the robot can process to recognize objects, detect motion, and understand visual cues in the environment. Vision cameras are particularly useful for tasks that require detailed visual information, such as identifying specific objects or interpreting human gestures. However, the effectiveness of vision-based systems can be influenced by factors such as lighting conditions and object visibility [28].

In comparing the capabilities of LiDAR sensors and vision cameras, researchers have observed that both technologies currently offer effective solutions for environmental sampling and analysis. LiDAR excels in providing high-precision 3D mapping, while vision cameras offer rich visual data that can be used for object recognition and scene interpretation. For the widely applied vision camera, a nonlinear optimization of optical camera multiparameter made it has more clear vision when scanning around and collecting environmental data [29]. Several enhancements have been introduced to the original Gradient-based optimizer (GBO). Firstly, during the exploration phase, a fitness-distance balance is employed to select the most influential candidate for guiding the solution update. Secondly, in the exploitation phase, a random search technique is implemented. The transition between the original mode and the additional mode is governed by a probability mechanism. Lastly, a neighborhood local search has also been incorporated. This optimization can help the robots have more clear vision and have better understanding about home environment.

3.2. Obstacle avoidance algorithm

Most companion robots for Alzheimer's patients are humanoid robots, including Peper robot, Nao robot, and Lio robot [25]. These robots are designed to operate in domestic environments, which are often characterized by complex spatial layouts and diverse furniture arrangements. In such settings, the ability of a robot to effectively navigate and avoid obstacles is of paramount importance [11]. Obstacle avoidance is a critical function that ensures the robot can move safely and efficiently within the home without causing damage to itself, the surroundings, or the objects it interacts with [30].

The obstacle avoidance functionality in robots generally comprises two main stages: the learning stage, where the robot acquires knowledge about its environment, and the query stage, where it uses this knowledge to navigate and avoid obstacles in real-time. Given the diversity of home environments, a wide range of obstacle avoidance algorithms have been developed and implemented in service robots to address various challenges [31].

Many of these home service robots are equipped with mechanical arms, which add another layer of complexity to the obstacle avoidance process. Mechanical arms must not only navigate the robot's body but also maneuver in tight spaces to interact with objects or perform tasks. Notable examples of such robots include the Pepper robot developed by SoftBank [24], known for its ability to engage in social interactions and perform simple tasks, and the ROBEAR robot developed by the RIKEN institute in Japan [32], which is designed to assist with caregiving tasks, such as lifting and moving patients.

Researchers and engineers have conducted extensive studies on the obstacle avoidance capabilities of these robotic arms, recognizing their importance in enhancing the safety and efficiency of home service robots. One significant contribution in this field is the development of a three-dimensional obstacle avoidance control design based on an integrated Particle Swarm Optimization (PSO) algorithm. This innovative approach, proposed by a team from National Cheng Kung University, has been successfully applied to home service robots. The new PSO algorithm stands out due to its superior performance compared to traditional PSO methods; it exhibits the smallest standard deviation and the fastest convergence speed. In practical experiments, this algorithm has proven capable of guiding the robot to its target position smoothly, even in environments with multiple obstacles, thus demonstrating its effectiveness and reliability [12].

In addition to the PSO-based approach, another noteworthy development is a robot manipulator obstacle avoidance algorithm grounded in decision-making power. This algorithm integrates a closed-loop control system, dynamic repulsive fields, and decision-making power to create a highly flexible online adaptation framework. This framework ensures the safety of the robot's end effector and joints, crucial for delicate operations within confined spaces. The algorithm has shown impressive results, exhibiting effectiveness, robustness, and smooth operation in both simulation scenarios and physical experiments [12]. These advancements not only enhance the capability of home service robots to perform complex tasks safely but also push the boundaries of what these robots can achieve in real-world domestic environments.

Overall, the continuous improvements in obstacle avoidance algorithms are making home service robots more adept at handling the intricacies of home environments.

3.3. Human-computer interaction

Human-Computer Interaction (HCI) is a multidisciplinary field that focuses on the design, evaluation, and implementation of interactive computing systems intended for human use. It also explores the fundamental phenomena associated with these interactions. As service robots become increasingly integrated into various aspects of our daily lives, the significance of HCI has grown exponentially. This field plays a crucial role in ensuring that these robots can interact seamlessly with humans, providing services that are intuitive, efficient, and responsive to our needs [13].

Currently, the primary methods of human-computer interaction in home service robots involve the use of advanced sensory technologies. These robots are typically equipped with visual sensors and auditory sensors that enable them to perceive and understand their environment, as well as the humans they serve [28, 33].

Visual sensor-based interaction is a key aspect of HCI in service robots. This form of interaction predominantly relies on image processing technologies, which allow the robot to interpret and analyze visual data. For instance, through the use of cameras and sophisticated image recognition algorithms, a robot can detect and identify objects, recognize faces, interpret gestures, and navigate its environment. These capabilities are essential for performing tasks such as picking up objects, following human commands, or even understanding non-verbal cues like hand signals or facial expressions [28]. The effectiveness of this interaction hinges on the accuracy and speed of the robot's visual processing, which is an area of ongoing research and development [34]. Recently, an ultra-range gesture recognition (URGR) in HCI technique has been proposed [35]. According to the research, the existing gesture recognition methods are not feasible at distances exceeding 7 meters and are typically limited to indoor environments. The limitations of existing gesture recognition methods mainly stem from the combination of low resolution and lighting factors. As the distance between the camera and the subject increases, the resolution of the captured image decreases. Indoor environments often bring challenges related to lighting conditions. After using Super Resolution (SR) algorithm and Generative Adversarial Network (GAN) to guide image restoration to reconstruct details, robots are able to see objects 25 meters long [35]. This optimization makes robots have further vision and better understanding about human instructions.

Auditory sensor-based interaction is another critical component of HCI, enabling robots to communicate with humans through speech and sound. This interaction is largely dependent on natural language processing (NLP) technologies, which allow the robot to understand and generate human language. Through microphones and advanced NLP algorithms, service robots can listen to spoken commands, interpret their meaning, and respond appropriately. This capability is crucial for tasks such as following verbal instructions, engaging in dialogue, or even providing voice-based reminders and alerts [33]. The success of auditory interactions depends on the robot's ability to accurately interpret spoken language, even in noisy environments or when dealing with diverse accents and speech patterns [36].

While these sensory and processing technologies have greatly enhanced the capabilities of service robots, certain challenges remain in optimizing the quality and effectiveness of human-computer interaction. Two notable phenomena that impact HCI in service robots are the reduced agency effect and the uncanny valley effect [37, 38].

The reduced agency effect refers to a situation where users feel a diminished sense of control or involvement when interacting with autonomous systems. In the context of service robots, this can occur if the robot's actions seem overly automated or disconnected from the user's input, leading to a less satisfying interaction experience [37]. The uncanny valley effect is another significant factor in HCI, particularly in interactions involving humanoid robots. This effect occurs when a robot's appearance or behavior is almost, but not quite, human-like, resulting in a sense of unease or discomfort among users [38]. Considering the particularity of Alzheimer's disease patients, it is necessary to minimize the design of robots reduced agency effect and uncanny valley effect as much as possible.

As service robots continue to evolve, HCI will remain a vital area of focus, ensuring that these robots can interact with humans in ways that are natural, effective, and comfortable.

4. Conclusion

The rapid development of home service robots signifies a transformative shift in the landscape of home automation. From the introduction of the Roomba in 2002 to the advanced floor cleaning and companion robots of today, these technologies have evolved to meet the growing demands of modern households. The integration of AI, sensor technology, and human-computer interaction has enabled robots to perform a wide array of tasks autonomously, thereby enhancing convenience, improving the quality of life, and providing critical assistance to vulnerable populations, such as Alzheimer's patients.

As the technology continues to mature, the further innovations that will expand the capabilities of home service robots can be expected. These robots are likely to become even more intelligent, adaptive, and capable of interacting with humans in increasingly natural and effective ways. The future of home service robots will likely involve more personalized and context-aware systems that can cater to the unique needs of individual households.

However, several challenges remain, particularly in areas such as obstacle avoidance, human-computer interaction, and the ethical implications of robots in caregiving roles. Addressing these challenges will require ongoing research, collaboration between technologists and ethicists, and a user-centered approach to design.

In conclusion, the application of service robots in home automation is set to grow significantly, driven by technological advancements and societal needs. As these robots become more sophisticated and integrated into daily life, they will not only automate mundane tasks but also provide critical support in caregiving, making them indispensable in the smart homes of the future.

References

[1] Engelhardt, K. G., et al. "Human-robot integration for service robotics." Human-robot interaction. Taylor & Francis Ltd., London, UK, 1992.

[2] Executive Summary World Robotics 2017 Service Robots. 2018.

[3] Sylla, Cristina, et al. “Smart Toys, Smart Tangibles, Robots and Other Smart Things for Children.” International Journal of Child-Computer Interaction, vol. 33, Sept. 2022, p. 100489, https://doi.org/10.1016/j.ijcci.2022.100489. Accessed 9 June 2022.

[4] Ou Yang, Fang-Chuan, et al. “Effect of Augmented Reality-Based Virtual Educational Robotics on Programming Students’ Enjoyment of Learning, Computational Thinking Skills, and Academic Achievement.” Computers & Education, vol. 195, 1 Apr. 2023, p. 104721, www.sciencedirect.com/science/article/abs/pii/S0360131522002925, https://doi.org/10.1016/j.compedu.2022.104721.

[5] Pouyan Esmaeilzadeh, and Mahed Maddah. “Robotic Companions and Healthy Aging: A Mixed-Methods Exploration of Older Adults’ Perspectives and Insights.” Technology in Society, vol. 78, 1 Aug. 2024, pp. 102689–102689, https://doi.org/10.1016/j.techsoc.2024.102689. Accessed 19 Aug. 2024.

[6] Zeng, Ying, et al. “Retrospective of Interdisciplinary Research on Robot Services (1954–2023): From Parasitism to Symbiosis.” Technology in Society, vol. 78, 1 Sept. 2024, pp. 102636–102636, https://doi.org/10.1016/j.techsoc.2024.102636. Accessed 19 Aug. 2024.

[7] Wang, Qi, et al. “Multi-Style Learning for Adaptation of Perception Intelligence in Home Service Robots.” Pattern Recognition Letters, vol. 151, Nov. 2021, pp. 243–251, https://doi.org/10.1016/j.patrec.2021.08.026. Accessed 10 Apr. 2022.

[8] Keating, Norah. "A research framework for the United Nations Decade of Healthy Ageing (2021–2030)." European Journal of Ageing 19.3 (2022): 775-787.

[9] Vaussard, F., et al. “Lessons Learned from Robotic Vacuum Cleaners Entering the Home Ecosystem.” Robotics and Autonomous Systems, vol. 62, no. 3, Mar. 2014, pp. 376–391, https://doi.org/10.1016/j.robot.2013.09.014.

[10] M, Manasa, et al. “Smart Vacuum Cleaner.” Global Transitions Proceedings, vol. 2, no. 2, 1 Nov. 2021, pp. 553–558, www.sciencedirect.com/science/article/pii/S2666285X21000790#:~:text=Anbumani%20V%20et%20al%20proposed%20a%20paper%20%E2%80%9CDevelopment, https://doi.org/10.1016/j.gltp.2021.08.051.

[11] Hua, Bin, et al. “Human-like Artificial Intelligent Wheelchair Robot Navigated by Multi-Sensor Models in Indoor Environments and Error Analysis.” Procedia Computer Science, vol. 105, 1 Jan. 2017, pp. 14–19, https://doi.org/10.1016/j.procs.2017.01.181. Accessed 19 Aug. 2024.

[12] Zhang, Wei, et al. “An Obstacle Avoidance Algorithm for Robot Manipulators Based on Decision-Making Force.” Robotics and Computer-Integrated Manufacturing, vol. 71, no. 71, 1 Oct. 2021, pp. 102114–102114, https://doi.org/10.1016/j.rcim.2020.102114. Accessed 14 Jan. 2024.

[13] Hewett, Thomas T., et al. ACM SIGCHI curricula for human-computer interaction. ACM, 1992.

[14] Asafa, T.B., et al. “Development of a Vacuum Cleaner Robot.” Alexandria Engineering Journal, vol. 57, no. 4, Dec. 2018, pp. 2911–2920, www.sciencedirect.com/science/article/pii/S1110016818300899, https://doi.org/10.1016/j.aej.2018.07.005.

[15] Jignesh Sindha, et al. “Rigid Body Modeling of Three Wheel Vehicle to Determine the Dynamic Stability — a Practical Approach.” IEEE International Transportation Electrification Conference, 1 Aug. 2015, https://doi.org/10.1109/itec-india.2015.7386889. Accessed 28 June 2023.

[16] Kim, Jung-Hoon, and Jun-Ho Oh. “Design and Analysis of Rotary MR Damper Using Permanent Magnet: 2nd IFAC Conference on Mechatronic Systems, Berkeley, CA, USA, 9-11 December.” IFAC-

PapersOnLine, vol. 35, no. 2, 1 Dec. 2002, pp. 823–827, https://doi.org/10.1016/s1474-6670. Accessed 19 Aug. 2024.

[17] Zhang, Guozhi, et al. "Research on Ultrasonic-Electromagnetic Wave Simultaneous Sensing Sensors." Sensors and Actuators a Physical, vol. 374, 1 Aug. 2024, pp. 115446–115446, https://doi.org/10.1016/j.sna.2024.115446. Accessed 19 Aug. 2024.

[18] Giuliano, Romeo, et al. "MuSLi: A Multi Sensor LiDAR Detection for C-V2X Networks." Computer Networks, vol. 221, Dec. 2022, p. 109514, https://doi.org/10.1016/j.comnet.2022.109514. Accessed 14 Dec. 2022.

[19] Kim, Jonghoek. "Autonomous Robot Vacuum System Composed of a Cleaner Robot and a Dust Storage Robot." Journal of the Franklin Institute, vol. 361, no. 11, 1 June 2024, pp. 106938–106938, https://doi.org/10.1016/j.jfranklin.2024.106938. Accessed 11 July 2024.

[20] Alzheimer's Association. 2024 Alzheimer's Disease Facts and Figures. Alzheimer's Association, 2024.

[21] Abdelnour, Carla, et al. "[P4–322]: ARE THERE DIFFERENCES in the OPINION of PATIENTS with ALZHEIMER DISEASE and THEIR CAREGIVERS about HAVING SUPPORT from a SERVICE ROBOT at HOME?" Alzheimer S & Dementia, vol. 13, no. 7S_Part_29, 1 July 2017, https://doi.org/10.1016/j.jalz.2017.06.2192. Accessed 19 Aug. 2024.

[22] Fischinger, David, et al. "Hobbit, a Care Robot Supporting Independent Living at Home: First Prototype and Lessons Learned." Robotics and Autonomous Systems, vol. 75, Jan. 2016, pp. 60–78, https://doi.org/10.1016/j.robot.2014.09.029.

[23] "Low Cost Automation." Igus.eu, 2024, www.igus.eu/robolink/robot. Accessed 30 Aug. 2024.

[24] aldebaran. "Pepper the Humanoid and Programmable Robot | SoftBank Robotics." Www.aldebaran.com, www.aldebaran.com/en/pepper.

[25] Faisal, Mohammed, et al. "Robot-Based Solution for Helping Alzheimer Patients." SLAS Technology, vol. 29, no. 3, 1 May 2024, pp. 100140–100140, https://doi.org/10.1016/j.slast.2024.100140. Accessed 13 May 2024.

[26] Abdelnour, Carla, et al. "P2-399: RAMCIP PROJECT, a ROBOTIC ASSISTANT to SUPPORT ALZHEIMER'S DISEASE PATIENTS at HOME: A NOVEL APPROACH in CAREGIVING." Alzheimer's & Dementia, vol. 12, no. 7, 1 July 2016, https://doi.org/10.1016/j.jalz.2016.06.1610. Accessed 4 July 2023.

[27] Sauer, Florian, et al. "Development of an Analytical Model for Correlation with Workpiece Roughness in Stream Finishing Using a LiDar Sensor." Procedia CIRP, vol. 123, 1 Jan. 2024, pp. 238–243, https://doi.org/10.1016/j.procir.2024.05.043. Accessed 19 Aug. 2024.

[28] Wang, Shun, et al. "Effects of Camera External Parameters Error on Measurement Accuracy in Monocular Vision." Measurement, vol. 229, 1 Apr. 2024, pp. 114413–114413, https://doi.org/10.1016/j.measurement.2024.114413. Accessed 19 Aug. 2024.

[29] Sun, Kangjian, et al. "Nonlinear Optimization of Optical Camera Multiparameter via Triple Integrated Gradient-Based Optimizer Algorithm." Optics & Laser Technology, vol. 179, 1 Dec. 2024, pp. 111294–111294, https://doi.org/10.1016/j.optlastec.2024.111294. Accessed 30 Aug. 2024.

[30] Aizat, Muhammad, et al. "A Comprehensive Review of Recent Advances in Automated Guided Vehicle Technologies: Dynamic Obstacle Avoidance in Complex Environment toward Autonomous Capability." IEEE Transactions on Instrumentation and Measurement, vol. 73, 2024.

[31] Kavraki, L.E., et al. "Probabilistic Roadmaps for Path Planning in High-Dimensional Configuration Spaces." IEEE Transactions on Robotics and Automation, vol. 12, no. 4, 1996, pp. 566–580, https://doi.org/10.1109/70.508439.

[32] Wilkinson, Jens. "The Strong Robot with the Gentle Touch | RIKEN." Www.riken.jp, 23 Feb. 2015, www.riken.jp/en/news_pubs/research_news/pr/2015/20150223_2/.

[33] Wu, Stephen, et al. "Deep Learning in Clinical Natural Language Processing: A Methodical Review." Journal of the American Medical Informatics Association, vol. 27, no. 3, 3 Dec. 2019, pp. 457–470, academic.oup.com/jamia/article-abstract/27/3/457/5651084, https://doi.org/10.1093/jamia/ocz200.

[34] Yang, Ping, et al. "Bit Rate Selection Technology of Image Processing Based on Artificial Intelligence in MPEG-DASH Adaptive Streaming Media." Journal of Radiation Research and Applied Sciences, 1 Aug. 2024, pp. 101036–101036, https://doi.org/10.1016/j.jrras.2024.101036. Accessed 19 Aug. 2024.

[35] Eran Bamani, et al. “Ultra-Range Gesture Recognition Using a Web-Camera in Human–Robot Interaction.” Engineering Applications of Artificial Intelligence, vol. 132, 1 June 2024, pp. 108443–108443, https://doi.org/10.1016/j.engappai.2024.108443. Accessed 4 July 2024.

[36] Lázaro, Esther, et al. “Efficiency of Natural Language Processing as a Tool for Analysing Quality of Life in Patients with Chronic Diseases. A Systematic Review.” Computers in Human Behavior Reports, vol. 14, 1 Mar. 2024, pp. 100407–100407, https://doi.org/10.1016/j.chbr.2024.100407.

[37] Ciardo, Francesca, et al. “Reduced Sense of Agency in Human-Robot Interaction.” Lecture Notes in Computer Science, vol. 11357, 28 Nov. 2018, pp. 441–450, https://doi.org/10.1007/978-3-030-05204-1_43. Accessed 29 Apr. 2023.

[38] Mori, Masahiro, et al. “The Uncanny Valley [from the Field].” IEEE Robotics & Automation Magazine, vol. 19, no. 2, June 2012, pp. 98–100, ieeexplore.ieee.org/abstract/document/6213238, https://doi.org/10.1109/mra.2012.2192811.