RESEARCH ARTICLE

REVISED Robot-assisted homecare for older adults: A user study on needs and challenges [version 2; peer review: 2 approved with reservations, 1 not approved]

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Abstract

Background

As the older adult population increases there is a great need of developing smart healthcare technologies to assist older adults. Robot-based homecare systems are a promising solution to achieving this goal. This study aims to summarize the recent research in homecare robots, understand user needs and identify the future research directions.

Methods

First, we present an overview of the state-of-the-art in homecare robots, including the design and functions of our previously developed ASCC Companion Robot (ASCCBot). Second, we conducted a user study to understand the stakeholders' opinions and needs regarding homecare robots. Finally, we proposed the future research directions in this research area in response to the existing problems.

Results

Our user study shows that most of the interviewees emphasized the importance of medication reminder and fall detection functions. The stakeholders also emphasized the functions to enhance the connection between older adults and their families and friends, as well as the functions to improve the efficiency and productivity of the caregivers. We also identified three major future directions in this research area: human-machine interface, learning and adaptation,

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and privacy protection.

Conclusions

The user study discovered some new useful functions that the stakeholders want to have and also validated the developed functions of the ASCCBot. The three major future directions in the homecare robot research area were identified.

Keywords
Elderly care, companion robot, human-robot interaction, health care, user study, medication reminder, fall detection

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REVISED **Amendments from Version 1**

Compared with the previous version, this version has the following modifications:

1. The title was updated as "*Robot-assisted homecare for older adults: A user study on needs and challenges*".

2. In the introduction section, discussions about previous studies investigating different stakeholders' perceptions were added, and the contribution of our work was clarified.

3. In the Existing robots section, the literature was expanded with results from previous research studies.

4. In the User study section, the information about how the participants were accessed and recruited, the inclusion/exclusion criteria, and how the interview data was coded were added. The definitions of the three groups of users were clarified.

5. In the Summary section of the user study, we included the interviewees' expectations and concerns regarding the robot obtained from the interviews.

Any further responses from the reviewers can be found at the end of the article

Introduction

The home healthcare industry is under growing pressure to modernize services through new technologies. Over the next decade, 18 million Americans will turn 65 (15% increase from 2020 figures)[1]. When people get older, many of them suffer various problems such as mobility decline, cognition impairment, and physical health deterioration[2–5], which make it unsafe for them to live alone. Therefore they have to rely on the assistance of family members and caregivers, which creates a significant burden on their family and the home healthcare industry. Providing efficient, cost-effective home healthcare for this growing group of older adults has great societal impact and requires major changes in ways providers gather information from and deliver care services to care recipients. The COVID-19 pandemic has further contributed to an urgent need for innovating the home healthcare industry[6].

To address this gap, providers will need technologies that incorporate sensing, computation, and communication, along with a broad spectrum of technological interventions for healthcare delivery[7]. Robotic homecare technologies can record health-related data from the care recipients and their environment with advanced sensors, and then automatically process the data and provide personalized advice or automated interventions[8]. These technologies allow for individualized care that promotes independence and safety of the care recipients[9]. For healthcare workers, these technologies reduce their workload and improve their productivity, therefore allowing them to focus on the more complex aspects of their work.

The goal of the work reported in this paper is three-fold: 1) presenting an overview of the state of the art of homecare robots, with a focus on our customized companion robot; 2) conducting a user study to understand the needs of different stakeholders in the home healthcare industry; and 3) identifying the future research directions in developing truly smart and practical robot-based homecare systems.

There are some previous studies that investigated stakeholders' perceptions and needs mainly based on online survey. For example, Yuan *et al.*[9.1] conducted an online questionnaire-based survey to understand the acceptability and users' needs of humanoid robots in helping people with Alzheimer's disease and related dementias (ADRD). They found that people living with ADRD, caregivers, and the public have favorable attitudes regarding the use of robots for individuals with ADRD. The three most mentioned functions are medication reminders, emergency call services, and assistance in contacting medical services. Hall *et al.*[9.2] conducted a survey to understand acceptance and perceived usefulness of tasks performed by robots among young, middle-aged, and older adults. They found a significant difference between younger adults and older adults, showing that the former are more willing to accept robot-assisted healthcare in hospitals. Ziefle *et al.*[9.3] explored if older adults would accept a robotic assistant at home through an online survey. They found that the overall acceptance of robots is high. However there is concern about the technical defects and maintenance costs. Some functions are still preferred to be done with human helpers, such as eating food or taking medicine. Other functions like escorting users to bed or assisting users to use the toilet are preferred to be accomplished by a robotic nurse.

Comparing with the existing literature, our work has the following contributions. First, the purpose of this work is not purely a user study. Our work aims to summarize the recent research in homecare robots, understand user needs through user study and identify the future research directions, which is new compared with the existing work. Second, our user study has new findings from the interview. It not only shows that most of the interviewees emphasized the importance of the medication reminder and fall detection functions, but it also identifies new functions that the stakeholders want to have. These include features to enhance the connection between older adults and their family members and friends, such as photo sharing, social media, and daily communication. Additionally, functions to improve the efficiency and productivity of the caregivers are highlighted, such as health data sharing and telehealth. Besides, we also found that the interviewees expected the robots to be user-friendly, adaptable, and privacy-protective. Third, based on the interviews and the existing research work, we identified the major future directions in this exciting research area, which have not been discussed in previous user studies.

State of the art

Researchers around the world have been actively developing homecare robots in recent years in an effort to help older adults live an independent and quality life[10]. Below is a brief review of some of the notable projects and products.

Existing robots

Improving communication between older adults and their informal and formal caregivers is an important function of homecare robots. Several robots have been developed for this

purpose. A robot named Giraff[11] enables older adults to make video calls to their caregivers who can then remotely control the robot to check the situation. The GiraffPlus robot[12] can monitor users' activities and physiological signals. However, the caregiver must constantly attend the patient and remotely control the robot. Pepper is a social humanoid robot developed by Softbank[13] which can recognize human faces and emotions. It has a touchscreen, arms, fingers, and a mobile base. When used for elderly care, Pepper can provide simple instructions regarding exercise, share medical information with caregivers, conduct dementia training program combined with a tablet PC[13.1], enable multimodal interaction to facilitate the adoption and usage of the robot by persons living with dementia[13.2] and connect with family members and friends through its telepresence function. SHAPES H2020[13.3] is an European Union-funded project that aims to build an ecosystem with large scale of digital solutions to support the independent living for older adults with health issues. One of the pilot studies of this project is to use the social robot ARI[13.4] to promote the wellbeing of people with early-stage dementia. The robot can offer cognitive activities depending on older adults' needs. Healthcare professionals and caregivers are also connected to the robot to set up the activities. ENRICHME H2020[13.5] is another project aiming to provide long-term human monitoring and interaction for the elderly with a mobile service robot. In this project, a thermal camera enhanced the multi-sensor human perception of the assistive robot, and an RFID ecosystem is used to locate personal items in the user's home environment. The assistive robot also provides other features such as non-intrusive physiological monitoring, cognitive games, and video calls. The GrowMeUp project[13.6] aims to provide assistance and companionship to elderly people. It can enhance the connection between older adults and their family members and caretakers, enabling them to stay active through various technologies such as teleconference or the social facilities provided by the robot itself.

Powered by natural language understanding, conversational social robots can be used in homecare for different purposes. ElliQ is a commercial companion robot for elderly care[14]. It can be used for entertainment and health-related tasks such as setting and tracking wellness goals, assessment of general health, and playing cognitive games. Robot-based clinical interviews can be administered to assess patients' physical and mental health and provide timely intervention. Do *et al.*[15] developed a clinical screening interview robot for older adults. The implemented functions include pain rating, cognitive evaluation, and fall risk evaluation, etc. Andriella *et al.*[16] proposed a robot to detect, assess, and quantify cognitive impairments like Alzheimer's disease and mild cognitive impairment. The Flo robot[17] can conduct natural language-based conversations with care recipients to provide suggestions regarding activities of daily life. Mini is a social robot with an animal-like furry skin[18], which is designed to assist older adults in their daily life. Su *et al.*[19] implemented a conversation-based medication management system for older adults, which allows caregivers to use a tabletop companion robot to manage care recipients' medication. An updated version of this robotic medication management system allows the robot to adapt to different users through reinforcement learning[20]. Lotfi *et al.*[21] employed a social robot as an exercise trainer to guide, monitor and evaluate older adults' exercise. The robot can give feedback through facial expressions and voice. Other conversational robots are designed to provide emotional support for persons with dementia. The robot CuDDler[22] promotes social engagement and reduces behavioral and psychological symptoms of dementia. The Ludwig robot[23] can interact with dementia patients by asking them questions, asessing their answers and reporting back to caregivers on their condition.

There is also a significant amount of recent work in developing homecare robots that deliver healthcare services. For example, Li *et al.*[24] study automated bandaging for homecare using a robotic arm. They developed a force-position decoupling control strategy to achieve the full process of bandage tension control, bandaging trajectory adjustment and following. Robot-based rehabilitation has been researched by many groups. Garzo *et al.*[25] developed ArmAssist, a telerehabilitation platform to help post-stroke subjects maintain the rehabilitation of the upper limbs at home. Sun *et al.*[26] realized a walking training robot which caters to the characteristics of human walking and allows passive and active training to be directly and gently switched during walking. Infarinato *et al.*[27] developed a rehabilitation system that provides neurorehabilitation exercises and assessments to chronic stroke patients with aphasia, enabling the administration of speech and language home therapy. Paro is a therapeutic robot that has a harp-seal shape[28]. With different embedded sensors, Paro can sense the environment and has been used to help older adults with dementia[29].

ASCC Companion Robot

The authors have previously developed a prototype homecare robot called ASCC Companion Robot (ASCCBot)[15] in the Laboratory for Advanced Sensing, Computation and Control (ASCC Lab) at Oklahoma State University, which is shown in Figure 1. Featuring a tabletop design, this robot was built especially for older adults. It can connect with wearable devices and sensors in smart homes for health monitoring. In addition, through the conversational interface, the robot can conduct cognitive assessment, mental health and falling risk evaluation, etc. These features make ASCCBot innovative and useful when compared to existing robots/research.

ASCCBot functions: Previously, we implemented a variety of functions in our ASCCBot to provide different services for older adults. The robot has some basic functions such as playing music and news, telling jokes and quotes, reporting the weather and playing interactive games like rock-paper-scissors. With this robot, older adults can send voice messages to friends, take photos and post them on Twitter. The robot can also act as an interpreter between different languages. Considering that older adults may be lonely or bored when staying at home, a chit-chat function was also developed. The robot can also recognize the user through facial recognition and track the user's movement. Some of the function demonstrations are shown on our lab website at 30.

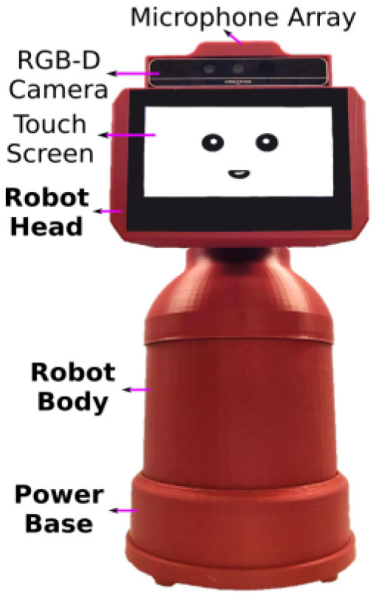

Figure 1. The ASCCBot companion robot. This figure is reproduced with permission from 15 with a license number of 5503360232048.

To improve the socioemotional well-being of older adults, a negative emotion management system[31] was implemented in the robot. The robot can recognize a user's negative emotions through an electrocardiogram (ECG) signal sent from a wearable device worn by the user. Recurrence quantitative analysis (RQA) is used to extract features from the raw ECG signal and a machine learning method is used to make a classification of emotions. When a negative emotion is detected, the robot engages the user in conversation as a way of emotion regulation to get the user out of the negative mood. The robot can also conduct pain evaluation and cognitive assessment[15] through a clinical interview process. The assessment results are then reported to the caregivers.

To help older adults improve the medication adherence, we proposed a medication reminder system[19] in which the robot serves as an agent to connect the older adult with the caregivers or family members for medication management. Using a mobile APP, caregivers or family members can create reminders, check medication adherence, record medication history and modify reminders for older adults. The older adults can also create reminders for themselves. The robot initiates a conversation to remind the older adult to take medicine at the scheduled times. The medicine and dosage will be recorded and caregivers can check it through the APP. The human subject test results indicate that the participants have a high satisfaction level with the system in terms of its usefulness and convenience.

Fall detection is a very important function in elderly care. Since the ASCCBot has a limited sensing range, it is not possible for it to detect falls when the older adult is not nearby. While many fall detection solutions rely on wearable motion sensors, they are not accurate and could generate many false alarms. Therefore we used both the robot and the wearable device for collaborative fall detection to achieve the best accuracy[32]. There are three parts in the collaborative fall detection system: the ASCCBot, a Wearable Monitoring Unit (WMU), and a healthcare management system. The WMU consists of an accelerometer, a mini camera, a microphone and a speaker. It can be worn at different locations on the human body, such as around the chest, on the wrist, etc. The WMU collects motion information to detect potential falls and sends captured images to the robot which runs a deep neural network to recognize falls using the images. The proposed algorithm achieves an overall accuracy of 84% for collaborative fall detection. It is also observed that the robot successfully sends out alarms to caregivers once the fall is confirmed.

Summary

Overall, there have been continuous efforts in developing robotic technologies for home healthcare, especially for older adults. However, current technologies are still far away from revolutionizing the current home healthcare practices, which can be attributed to the following major barriers. First, there is a great need to improve the human-machine interface (HMI) to make the robots more human-friendly. Most of the existing technologies are still at the laboratory stage and lack sufficient consideration of human factors such as human accessibility, perception capacity, and technological readiness, therefore greatly reducing care recipients' and healthcare provider's willingness to adopt them[33]. Second, the existing systems lack sufficient intelligence to fulfill the duties of an in-home assistant, especially health monitoring and intervention. This problem will most likely be resolved by leveraging the rapid progress in artificial intelligence (AI) technologies. Finally, privacy concern related to the use of robotic technologies in home environments has not been seriously addressed in the literature. Real world deployment of homecare robots demands satisfactory solutions to this important problem. The ASCCBot was built in our previous studies with several functions to help older adults. To fully develop the ASCCBot, we wanted to further explore different groups of users' requirements, see if the current robot's functions are still relevant, and identify more user needs to guide future research.

Methods

In this section, we present our recent user study regarding the functions of homecare robots.

Ethics statement

The user study interviews were approved by the Oklahoma State University IRB office under application No. IRB-22-252 dated July 1st, 2022. All interviewees were informed about our research objective and the purpose of the interview. They provided informed verbal consent before the interviews. The consent content includes the approval of the interview and the usage of interview content for publication. We told the interviewees that any information related to their identities would be removed both in the interview notes and the publication and they could refuse to answer any questions if they do not want to answer. Verbal consent was deemed

sufficient by the institutional review board because they thought the study posed minimal risk to participants. We asked each participant if he/she would agree to participate in the interview and allow us to use the interview content for publication. All participants agreed to do that. For each participant, we wrote down their name whether they agreed to attend the interview and whether they allowed us to use the interview content for publication.

User study

To understand the needs of the stakeholders in home healthcare, a user study was conducted from September 9, 2022 to October 7, 2022 in Stillwater, Oklahoma, USA. All authors are male and participated in the interviews. The first two authors are Ph.D. students and the last two authors are university professors with Ph.D. degrees. The team has backgrounds in both engineering and human sciences. The authors attended the interview training prior to the study. The majority (80%) of the interviewees know the interviewers. The participants were informed of the purpose of the user study. We also introduced our robot briefly by telling the stakeholders that we have a desktop companion robot used for elderly care purpose and the robot can see and hear older adults' activities, talk with older adults, and assist them with daily activities. We referred to Amazon's Echo Show/Alexa as an example so they can have a basic concept about the robot mentioned.

The study focused on the stakeholders of the proposed homecare robot who mainly fall into three groups. The first group consisted of older adults noted as future care recipients and potential direct end users. The second group consisted of caregivers who could utilize the robot to enhance productivity and efficiency in their daily caregiving tasks. The caregivers are the individuals who are trained and certified to provide care and assistance to the elderly, ill, disabled, or anyone in need of help with daily activities and medical needs. The third group were family members who could use the robot to better connect with their loved ones and provide care from a distance with reduced burden. They are usually the children or friends of the older adults. We reached out to older adults and family members from the local senior communities. We also reached out to the caregivers in the local hospitals and assistive living communities. The inclusion criteria for the interviewee are : 1) old adults who are 65 or above; 2) younger adults who have experience in taking care of older adults. The participants were interviewed either face-to-face or through teleconference. The interviews are semi-structured. The face-to-face interviews were conducted in a quiet public area. For some older adults, their families were present during the interview. The interview questions, prompts, and guides were provided by the authors. There is no repeat interview. For the teleconference interviews, the interviews were recorded with the permission of the participants. For the face-to-face interviews, notes were taken during the interviews. The notes were not returned to participants for comment or correction. One author coded the data by reading all the interview notes, abstracting the key points from the notes, counting, and calculating the statistical data of the key points and other authors checked and proved the data. The interview themes were identified in advance because we want our interview questions to fit the characteristics of the three groups and limit to the to the topic of in-home healthcare companion robot. Microsoft Excel was used to manage the data. The participants did not provide feedback on the findings.

A total of 31 users were interviewed, including n = 7 older adults who are between 65 and 82, n = 11 caregivers and n = 13 family members. All participants completed the interview successfully. Among them, n = 6 are males and n = 25 are females. The breakdown of interviewee is shown in Figure 2. Specific questions were prepared for each of the three groups (see *Extended data*. Besides the question regarding the desired functions of the robot, other questions query older adults' opinions on some proposed functions such as sharing photos between family members and older adults, use of chatting groups with caregivers, sharing health data with caregivers and family members. We also asked their familiarity and habit of using smart phones and social media. The interview lasted for about 30 minutes for each interviewee. Please note that the interview questions and associated data are available in data availability[34,35].

Results

Older adults

Figure 3 shows the most commonly mentioned functions that the older adults preferred the robots to have and the percentage of interviewees who mentioned them. The most important function that all older adults wanted was fall detection as older adults emphasized the importance of fall detection more than the function of photo sharing and receiving. They wanted the robot to be able to detect a fall event and immediately contact their caregivers, which is consistent with the fact that falls in older adults usually result in serious injuries or even death[36]. A majority of the interviewed old adults (86%) also mentioned that medication reminders are very useful to them. While it is obvious that medication adherence is important to one's health, we also found that many older adults also liked the robot to remind them about their daily activities, such as shopping and visiting doctors. This could be attributed to the fact that many older adults have poorer memory which causes troubles in tracking their daily schedules.

All the interviewees liked the idea of sharing photos with and receiving photos from their close family members. They felt that it would enhance social connection with their families and reduce loneliness from living alone. E.g., Interviewee 1 said he likes to receive photos of his grandchildren (content paraphrased) and Interviewee 12 said she would like to share some activities in a day with her family like sending pictures (content paraphrased). Regarding the use of social media, less than half (43%) of older adult participants reported that they seldom use it. Some older adults, between the age of 65 and 67, are good at using social media. E.g., Interviewee 12 said "I rely a lot on my smartphone whether it be Facetime, internet, or using apps. So, the smartphone is the way to go for me. I use it every day to talk and communicate." and Interviewee 29 mentioned that it is not difficult for him to use social networking apps (content

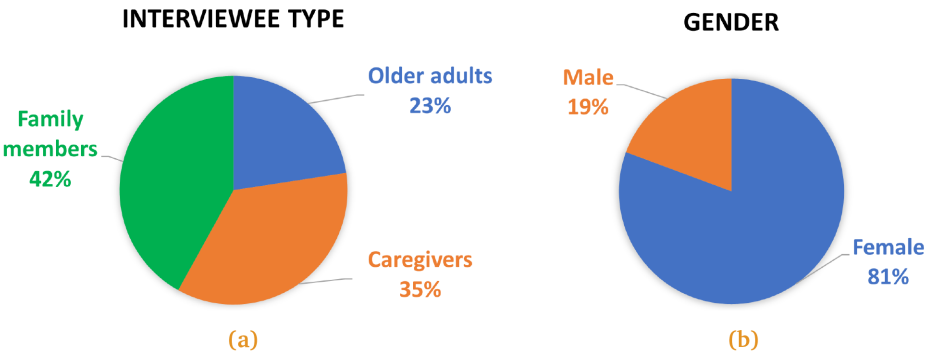

Figure 2. Interviewee demographics: (**a**) - Interviewee type; (**b**) - Interviewee gender.

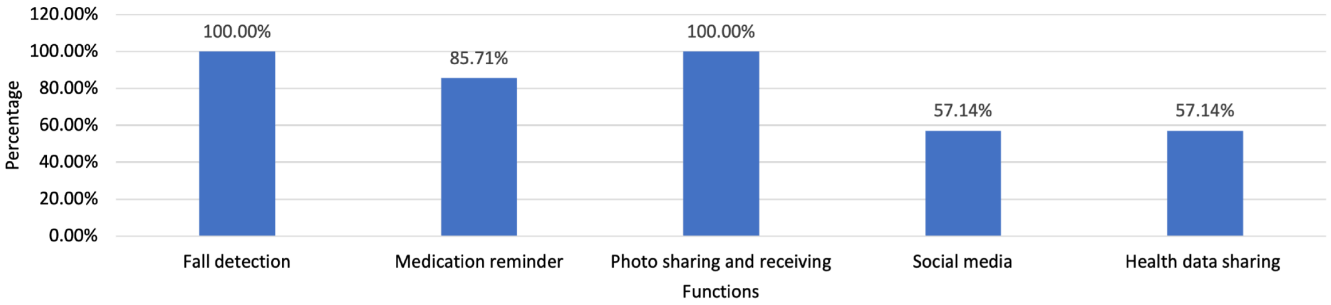

Figure 3. The most commonly mentioned functions by older adults.

paraphrased). More than half (57%) of the older adult participants noted they would like to share health vital data such as heart rate, blood pressure, blood sugar, body temperature, etc. with their close family members or caregivers on a regular basis. E.g., Interviewee 12 said she would like to share her health-related information (content paraphrased) and Interviewee 26 mentioned that she would like to share her blood pressure, body temperature, and blood sugar with families (content paraphrased). It is also found that nearly a third (29%) of the older adult participants expressed that they typically have difficulties in using new technologies like robots and smartphones and they may need assistance from others. Interviewee 1 said it is difficult sometimes to use social networking apps because he always forgets the password (content paraphrased). Interviewee 26 said she cannot use her cellphone because she has a hearing problem and sometimes even can not hear the doorbell. Her dog sometimes could help monitor the doorbell (content paraphrased).

Caregivers

The interviewed caregivers were either front-line workers with many years of experience or managers/owners of healthcare facilities like assisted living communities. Figure 4 shows the most desired functions that the caregivers want robots to have and the percentage of interviewees who mentioned those functions.

First, all caregivers indicated that the reminder function was very important for both caregivers and older care recipients. The most desired reminder involved medication reminding. In addition to reminding older adults to take medicine on time, they also wanted the robot to verify if older adults have taken the correct medicine with the right dosage at the right time. Some caregivers said that as older adults' health conditions change over time their medications may change accordingly, which makes is necessary to readily modify the reminders and keep them up-to-date. It is also possible that there may be drug interaction due to multiple medication prescriptions from different caregivers. A mechanism is needed to handle this situation. For example, Interviewee 15 said that "We have to perform two-hour checks on our patients. It would be great for the robot to send an alert to my phone 10–15 minutes ahead of time for the next check. These checks usually have to be performed on time and cannot be missed. When there are multiple patients with a lot of care needs, it's hard to remember who I have checked or who is next. So, a reminder for 2-hour patient checks would be nice. On the patient's end, a med reminder would be good. If there were a better way to determine who did not take a med or if meds were missed or given at the wrong times, this would be nice to know. Certain meds have to be taken within a certain time frame. So, reminding the patient when to take the med and when to dispense the med

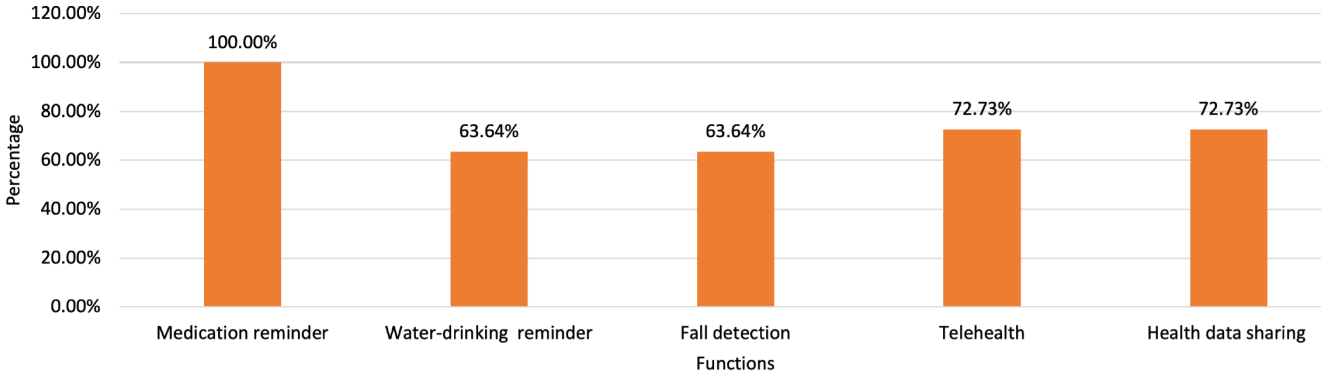

Figure 4. The most commonly mentioned functions by caregivers.

would also be good.". Interviewee 2 also mentioned that It is hard for them to ask people to take medication and food in time (content paraphrased). Therefore, reminders to patients and to caregivers are both important In addition, 64% of the caregivers reported the necessity of water-drinking reminder to diminish threat of dehydration among older care recipients. Other reminders like meal reminder, daily activity schedule reminder and exercise reminder were also mentioned. E.g., Interviewee 2 noted that older adults usually do not feel thirsty and it is better to create water-drinking reminders (content paraphrased). Interviewee 16 said that "Any type of sound or noise alert is good so that I know when the person gets up out of the bed, a chair, or trying to get up off the floor. It would be excellent to have some type of alert or reminder for the patient to get ready for meals or a reminder of the daily activity schedule. First, many are never ready to be taken down to breakfast, lunch, or dinner and some will miss the meal. I as the caregiver have to go get them. It takes extra time to get them ready but often time I do not have. So, a reminder with some verbal instructions to get prepared would be good. Second, patients are always asking me about their daily schedules. We have a large activity board for them to read and they get a weekly activity calendar in the form of a paper copy, but they hardly seem to ever remember what it is they could be doing day-to-day for leisure or entertainment. It would make them happier if they could participate in the activities rather than sit in their room or house. So, a "things to do" reminder would be nice."

Second, 64% of the caregivers emphasized the importance of the fall detection function. One participant, a nursing home manager, noted that during the night most caregivers are unavailable. Thus few persons are able to offer immediate or emergency assistance if the older adult falls. This may be one plausible reason some older adults prefer not to drink water despite feeling thirsty, since going to the bathroom may increase the risk of falling. The caregivers recommended that it is best for the robot to provide an accurate fall detection function and call emergency services, caregivers, or the older adult's families in a timely manner (content paraphrased). In addition, the caregivers mentioned that detecting the early symptoms of fall is also critical, which requires the robot to be able to conduct fall risk assessment through verbal conversation or analyze the gait of walking to predict imminent falls.

Third, a majority (73%) of the caregivers emphasized the usefulness of telehealth technologies, which can improve delivery of care provisions for those older adults residing in more rural areas, where there tends to be a greater shortage of healthcare providers. However, Interviewee 24 also expressed concerns: Some rural areas have poor internet connectivity, which makes teleconferences impossible. Also older adults and caregivers need to be educated on using telehealth technologies, as mentioned by Interviewees 7, 22 and 24. Telehealth also has its disadvantages. Older adults with hearing impairments may not be able to understand the caregivers during the online conversation. Privacy of information is another concern that accompanies the teleconference use. Both caregivers and care recipients may perceive that their conversations are being overhead by unknown people. These disadvantages associated with telehealth make people prefer in-person visit over telehealth.

Finally, regarding what kind of data the caregivers want to receive from their patients, some caregivers want to know the vital sign data, like blood pressure, body temperature, pulse or breath rate, etc., as mentioned by Interviewees 17 and 23. Some caregivers also care about the questions the patients may ask in order to have a better understanding of patients' needs. Again, privacy is a major concern when it comes to sharing health-related data, which should be properly addressed in the design of the homecare robot. E.g., Interviewee 22 said that "On a personal level, I think some type of monitoring aspect that brings up the whole privacy issue because older adults or most older adults value their privacy. However, for me personally, relative to my mother I would think that knowing where she is in the home or whether she had fallen would help.".

Family members

Figure 5 shows the most desired functions that the family members wanted robots to have and the percentage of interviewees who mentioned those functions.

Nearly half or 46% of family members mentioned that they usually use smartphones to make video calls to their older loved ones. E.g., Interviewee 3 said that she called her mother every two days but sometimes her mother missed her calls. Interviewee 5 said that her mother is 69 but still in a good health condition (content paraphrased). Therefore, her mother can use the cell phone very well. She likes to play Tiktok and do online shopping and they use a social App to contact each other. The frequency of calling can vary and depends on the extent of the older adult's health needs. Just under one-quarter or 23% of family members noted that their older parent is unable to use a normal smart phone due to the complexity and unfriendly user interface. E.g., Interviewee 11 said her grandparents are very old and live in a rural area so they can not use cell phones (content paraphrased). Interviewee 27 also noted that her mother can not use cell phones very well because she has hearing problems (content paraphrased). Therefore, smartphones with fewer functions, larger font sizes, and higher audio volumes would be more age-friendly.

Most family members (77%) cited a functional need to report emergency situations, especially in the case of falls. E.g., Interviewee 3 thinks that fall alters function can help make care-giving better and more efficient (content paraphrased). Interviewee 9 said "Fall detection and reporting is the most important information for elderly care". Interviewee 12 also mentioned that "An emergency alert on my phone that let me know when something is wrong with her like a fall, or if she is just having a bad day." Other emergency situations like myocardial infarction, stroke and heart attack were also mentioned (Interviewees 9 and 30). Most family members agreed that reminders are useful, especially medication reminder.

Over half (62%) of family members mentioned that it would be helpful if there was a device that could help older adults stay connected with their families, friends, or use social media. E.g., Interviewee 10 mentioned that older adults may feel lonely if living alone and socializing may be useful. Interviewee 4 noted that if older adults are living alone, they need communication with others to stay connected. It is also helpful if the robot could read the message from the friends of older adults. Over one-third (38%) of family members desired to receive photos shared by their loved ones. Finally, 69% of the family members mentioned that they would want timely access to an older parent's health information and activities of daily living (ADLs). The health information cited as useful included blood sugar, blood pressure, physical pain, heart rate, and body temperature. The ADLs include getting out of bed, having meals, using bathrooms, etc. In addition, behavioral anomalies like coughing, sneezing, etc. are also of interest as they are indicators of potential health issues. E.g., Interviewee 30 said that knowing ADLs of older adults like what they eat is helpful. The health information sharing by the robot is also a desirable function. Interviewee 28 mentioned that she would like the robot to send the data related to the well-being of her parents on a regular basis and said that "The health information would be helpful, like cough, blood sugar information, blood pressure information".

Summary

Overall, our user study shows that most of the interviewees in the three groups emphasized the importance of the medication reminder and fall detection functions, which validated the developed functions of the ASCCBot. We also identified new functions that the stakeholders want to have, which include the functions to enhance the connection between older adults and their families and friends, as well as the functions to improve the efficiency and productivity of the caregivers. Besides the desired function, the interviewees also mentioned their expectations and concerns regarding the robot. For example, Interviewee 15, 17 and 31 wanted the robot to be easy to set up and user friendly. Interviewee 2 and 20 pointed out that different older adults have different needs and preferences with respect to the robot functions. Therefore, it is better to make the functions adaptable. Interviewee 6, 8 and 22 mentioned their concerns regarding privacy issues.

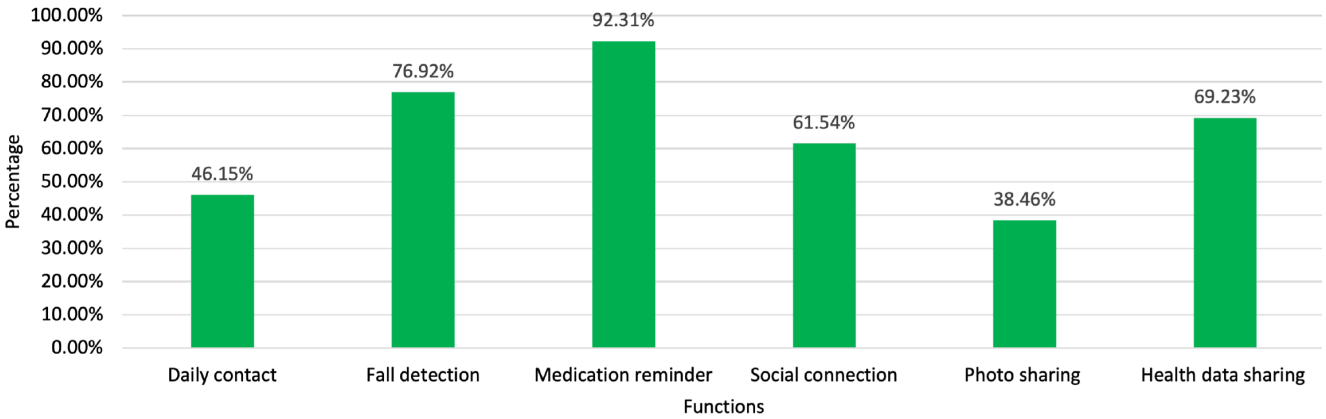

Figure 5. The most commonly mentioned functions by family members.

Discussion: Future research directions

The current research in homecare robots is still in its early stage and there exist many challenging problems ahead that should be solved before these robots are deployed into real homes to serve older adults. Our interviews also revealed that the interviewees expected the robots to be user-friendly, adaptable, and privacy-aware. In this section, we aim to identify the major future directions in this exciting research area based on the user study and the existing research work, which can serve as the guidelines when designing all robot functions.

Human-machine interface

Human-machine interface (HMI) mainly concerns the safety, communication, affection, and appearance of an engineered systems in relation to their users[37–39]. HMI impacts the users' experience with the system and eventually determines the acceptance of the system by the users. In robot-based homecare systems, the HMI consists of two parts: the care recipient interface and the caregiver interface.

The care recipient interface is mainly about the interaction between the robot and the care recipient. Older adults at an advanced age can be prone to memory loss[40], hearing loss[41], and difficulty in pronunciation due to tooth loss[42]. They may also suffer from other impairments, such as speech difficulties and vision degradation. Therefore it is necessary to develop age-friendly interfaces. First, to accommodate the cognitive capacity of older adults, it is necessary to improve the performance of natural language understanding of the robot. This may require 1) improved speech recognition that adapts to weaker voice and distorted pronunciation; 2) accomplishing the conversation task with less iterations; and 3) integrating as much context information as possible to reduce the unnecessary queries to the older adult. Second, it is important to develop age-friendly robot communication and listening skills. Like a human interviewer, a robot should have nondirective and directive listening responses. The former includes attending behaviors (eye contact, head posture, voice tone) and other behaviors that serve to establish a therapeutic alliance. The latter (feeling validation, interpretive reflection of feeling) helps bring the robot's perspective into the interview. It may be useful to leverage knowledge in human psychology to carry on an engaging conversation with older adults.

For the caregiver interface, there is a need to quantitatively define several essential attributes including communication, availability, reliability, and accuracy. Great attention will be paid to the following aspects: 1) data presentation and reporting: how to best present the care recipient's data for decision-making; 2) control and prescription: how to prescribe medication and therapies in a care recipient -friendly way so that services can be delivered to the care recipient through the robot. Metrics to be considered include the required learning effort and the burden or overhead on the caregivers due to the use of robot. It is also important to consider the issue of alert fatigue, as caregivers may be overwhelmed by frequent alerts and tend to ignore them eventually.

Learning and adaptation

Personalized healthcare requires that the robot have the ability to adapt to its users and environments. First, it is obvious that different users have different preferences and cognitive capacities which may change over time. However, most of the existing robots do not consider those situations[11,14–16,21,23], which reduces users' satisfaction with the robot. Therefore, it is desirable that the robot can gradually learn the preference of the older adults and the caregivers while adjusting their behaviors accordingly. The sensors on the robot allow them to recognize users' facial expressions, gestures, and sound events, which can be regarded as users' explicit or implicit feedback toward robots' services. The reinforcement learning algorithm can use the context information as a state and generate an action based on the state. The feedback can be considered as a reward to the robot's action. With this <state, action, reward > tuple, the model can be optimized to fit users preferences.

Second, there is a need for the robot to adapt to the environmental context, including: 1) the home environment the older adult resides in, which could be private-dwelling, assisted-living, or long-term care facilities; 2) the care recipient's health conditions; 3) their caregiving situation, such as living alone, living remotely from their caregivers in a rural community or living near their caregivers in more populated urban areas. These different environmental contexts may impose different requirements on the capabilities of the robot.

Various machine learning methods, especially continuous learning[43], transfer learning[44], and reinforcement learning[45], may offer potential solutions to augment the adaptation capability of the robots. With the natural language capability, the robot can actively seek input from the human users to help its learning. In our previous work[46,47], the robot asks the user for input when it is unable to recognize the event associated with a particular sound. Considering the difficulty of obtaining a large amount of labelled data, the robot can also use simulated data or leverage the data on the Internet through unsupervised learning.

Privacy protection

Privacy concerns involving homecare robots should be seriously addressed, as the robots are usually equipped with cameras, microphones and other sensors that may be considered intrusive to human privacy. Otherwise, such concerns may result in poor adherence to robot usage or changed user behaviors[48]. Privacy risks have been recognized as a major obstacle in deploying home service robots[48–50]. Our previous study[51] shows that older adults are concerned with the privacy risks against outside hackers or close friends who have access to the robots. According to an online user survey regarding privacy concerns using home robots[52], it is found that the top five privacy violations that people are most concerned are: nakedness of human body, identify theft, conversation, daily activity and emotions. Such concerns are significantly amplified when the robot is connected to the Internet, particularly when data is sent out to the Cloud. However,

given the importance of privacy protection, there are very few research efforts devoted to privacy protection in homecare robot settings[50].

For vision-related privacy concerns, it would be necessary to apply filters which remove sensitive information or scenes from the images or videos, which requires object recognition or scene understanding in the first place. However, training machine learning models to recognize sensitive data requires considerable labeled data, which may itself cause privacy concerns. Therefore, creating simulated data may be a solution to it. For audio-related privacy concerns, similar filtering mechanisms should be implemented to remove human voices irrelevant to the task at hand. In addition, it would be useful to implement certain courtesy protocols in the robots so that when sensitive situations are encountered, the robots will behave like their human counterparts, for example, turn away its camera to avoid keeping collecting data of the sensitive situation. Also, as the robots have different sensing modalities, it is desirable to use less-intrusive sensing modalities to observe or monitor the user or environment once sensitive situations occur.

On the other hand, it is also important to consider the privacy concern of caregivers and family members, as revealed through our user study. There is a need to avoid collecting sensitive scenes or conversations when caregivers and family members are interacting with their patients, or at least there should be informed consent before such data are collected.

Conclusions

In this paper, first, a brief overview of the state-of-the-art of the research in homecare robots is presented, which includes the ASCCBot platform developed in our lab. Second, a user study was conducted to understand the needs and opinions of the stakeholders including older adults, caregivers and family members regarding the robot functions. Third, we identified the future directions in this emerging area of homecare robots.

There is still limitation in our work. Although the user study informed our robot development, the sample size is still small. In our future research, we will conduct new user studies with larger sample sizes, which may be done through online survey. We hope this paper can inform and inspire the researchers to come up with new solutions that help promote the health, safety and quality of life of many home-bound care recipients.

Data availability

Underlying data

Figshare: Robot-assisted homecare: a user study on needs and challenges. https://doi.org/10.6084/m9.figshare.21893121.v5[34].

This project contains the following underlying data:

- User study interview records.docx (This file has the interview notes of 31 interviewees for the user study. Interviewees 7, 13, 14, 15, 16 and 22 were interviewed through teleconference, which was recorded, the anonymized transcripts are provided. The rest of the interviewees were interviewed in-person. We did not record those interviews. Instead, we took notes about their opinions on the interview questions which are provided. All notes and transcripts were anonymized. The document includes users' gender, type of participant [e.g. older adult, caregiver or family member], key insights, questions and answer notes).

Extended data

Figshare: Interview guide of the user study of Robot-assisted homecare: a user study on needs and challenges. https://doi.org/10.6084/m9.figshare.22223563.v1[35].

This project contains the following extended data:

- Interview guide.docx. (This file introduces the main questions that were asked during the interview for three types of interviewees: older adults, caregivers and family members).

Acknowledgements

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Open Peer Review

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Version 1

Reviewer Report 17 October 2023

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✗

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Summary
The authors present a user study on the needs and challenges of robot assistive technology. A user study is made in the form of an interview with a group of 31 people, divided into 3 groups: older adults, caregivers, and family members. Results are analyzed in groups separately. Authors identify also some future research directions.

Review
The review is organized concerning the three main goals of the paper defined by the authors:
“1)presenting an overview of the state of the art of homecare robots, with a focus on our customized companion robot;
2) conducting a user study to understand the needs of different stakeholders in the home healthcare industry; and
3) identifying the future research directions in developing truly smart and practical robot-based homecare systems.”

Ad 1 The presented state of Art is very basic and not complete. The section on Existing robots does not include all relevant citations, while the key for choosing described robots seems unclear. I would suggest extending the literature with results from previous research projects like SHAPES H2020 or ENRICHME H2020. I would strongly consider including the section about methods for user studies in HRI.

Ad 2 The Presented user study is questionable.
The number of participants is small, especially in the group of older adults. The groups are not defined clearly – there is no definition of a caregiver. There is no information on inclusion and exclusion criteria.

The user study is performed in the form of the interview without a fixed structure. The authors do not mention that in the paper. The interview guide of the user study is attached to the paper as

the link to Figshare, but according to the instruction “it is flexible to change according to the real situations”. It makes it hard to verify or replicate this study.

Authors should clarify why they chose this form of study and what is the advantage of using an open interview instead of a survey or questionnaire.

Results seem to be overly optimistic and far-reaching. For example, the Authors conclude that “The most important function that older adults wanted was fall detection”. There is no such question in the guide. Also, figure 3 shows that the most commonly mentioned functions by older adults are fall detection (100%) and photo sharing and receiving functions (100%), which makes the previous conclusion questionable.

Some remarks are manipulative and hard to understand: “Some older adults, especially those just over 60 years old”, while from the user study description “(...) n=7 older adults who are between 65 and 82”.

There is no discussion on results. I would suggest authors compare their results with previous studies on stakeholder’ perceptions.

Ad 3 Authors aimed to identify future research directions, but instead, they created a statement of what they consider as important. The conclusions do not match the results of the study.

Minor comments:
Authors use some buzzwords and generalizations, which do not bring new ideas or conclusions, i.e. in the abstract: the word “exciting” is used twice, or “the user study discovered some new useful functions”.

The words old adults, elderly adults, elderly, and patients are used as synonyms, I would propose using one of those – at least in the Results section.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
No

If applicable, is the statistical analysis and its interpretation appropriate?
No

Are all the source data underlying the results available to ensure full reproducibility?
No

Are the conclusions drawn adequately supported by the results?
No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Robotics, control theory, human-robot interaction

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Reviewer Report 16 October 2023

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Overview
The authors presented a user study to identify the needs of older adults with a focus on the potential of a robot supporting older adults at home. They interviewed older adults and other stakeholders such as caregivers and family members. Highlights of the functions the stakeholders mentioned were presented as well as a discussion of future research directions.

The overview of the state of the art of homecare robots presented was insightful and would be beneficial to a wide range of readers.
The results were also well presented.

Major comments

Title
The study focused on understanding the user needs of older adults and all stakeholders involved in caring for them. I would expect something related to older adults as the target care recipients to be reflected in the title. Homecare may not necessarily be for older adults only since there are robots that can provide healthcare services for people with mobility impairments at home, who are not older adults. There are rehabilitation robots designed for home care to support different forms of therapy for children, and other populations that are not necessarily older adults. This should therefore be clarified in the title and introduction as well.

Introduction
The third statement in the introduction (“When people get older, they suffer various problems such as mobility decline, cognition impairment, and physical health deterioration”) is too general and does not capture the heterogeneity of the older adult population. Not all older adults suffer those problems when they get older. There may be changes in perception, cognition, mobility

status, and health conditions but not all older adults necessarily experience declines or deterioration as the statement seems to portray. This statement as well as any other similar statements suggesting older adults as a homogenous population should be amended. Situations that are common may be pointed out and identified as situations that robot-assisted interventions could help with.

Methods
I observed that the prototype homecare robot (ASCC Companion Robot) described in the introduction was not referred to in the methods section while describing the user study. Was the robot introduced to the stakeholders interviewed? Were the functionalities demonstrated or described to the stakeholders? What was the robot reference provided to the stakeholders when the questions about the desired functions of 'the robot' was asked? (as mentioned in the last paragraph of the Methods section)

Data processing and analyses were not described. How were the interview data processed, transcribed, segmented, and coded? How was the coding scheme developed and what informed the different aspects coded in the interview? What qualitative analysis was conducted?

Discussion
There is not much connection between the results of the responses of the stakeholders and the discussion (future research directions). As an example, how do the priority functions mentioned by the older adults impact the design of the human-machine interface, learning and adaptation, etc? Another example - the majority of the caregivers (73%) emphasized the usefulness of telehealth technologies and some expressed their concerns. Are these opinions and concerns considered in the next future research directions discussed for caregiver interfaces? It would be great to see a better synergy between the needs expressed by the stakeholders and the next steps described in the future directions section.

On the whole, it was a well-prepared manuscript with insights that would benefit a diverse audience involving researchers, developers, caregivers, and care recipients as well.

Minor comments
Term for older adults
I see 'elders' in some parts of the paper. I would recommend that you keep it consistent as 'older adults'.

Page 8, second paragraph, second to the last statement – delete the 'a'
Interviewee 27 also noted that her mother can not use cell phones very well because she has hearing problems (content paraphrased).

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Human-robot interaction research. My research efforts and development focus on using robots, smart-home devices, and various other forms of technology to support independent living, healthcare needs, social interaction, successful aging, and everyday activities

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 01 August 2023

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The study firstly provided a summary of previous studies on homecare robots for aging populations and conducted a user study with three different groups of stakeholders to learn about the user requirements and needs of homecare robots. The authors gave a good description of the study results and a good discussion based on the results. The authors identified three major future directions in this robotic field: human-machine interface, learning and adaptation, and privacy protection. The results and discussion will be worthy to share in the robotic field. However, the following modifications will be needed before the manuscript can be indexed.

1. In the “existing robots” section, I would suggest to include some specific previous work using Pepper robot, for example, Schüssler *et al.,* (2020)[1]; Yuan *et al.,* (2022)[2].

2. This is a comment relating to both Introduction and Discussion: There are a number of previous studies investigating different stakeholders’ perceptions, needs and requirements, using different

approaches, such as survey and interview. I would suggest the authors:
- to clarify what's the new contribution of this work;
- to compare their findings with previous studies, for example, the following studies: Hall *et al.,* (2019)[3]; Ziefle & Calero Valdez (2017)[4]; Yuan *et al.,* (2022)[5]

3. In the "User study" section:
- Please provide more information on how you accessed and recruited participants and what are the inclusion/exclusion criteria. All these recruitment information can influence the study results.
- The second participant group in the study is "caregivers". Do you mean "paid and/or professional caregivers"? Please give a definition for the second and third group, so that readers can understand the difference in these two stakeholders, which impact their different requirements and needs for the homecare robots. These information will also help the authors and readers understand the participants' feedback.
- The authors used the "interview" method in the study. Is it unstructured, semi-structured, or structured interview? These three different approaches may lead to different interview results.
- Please give more details about how the author coded the interview data.
- Also, the authors mention that the "interview themes were identified in advance". Please use 1-2 sentences to explain why the authors chose to identify the themes in advance.

4. In "Results" section:
- Under the "caregivers" section, when presenting the caregivers' comments, the authors (or the caregivers) are using "patients" a lot. Which group of patients are meaning here?
- At the very end of the results section, the authors mentioned that the interview questions are available in "data availability". I would suggest to move it to the "Methods" section. A knowledge of your questions design will help the readers a lot to understand your study and your results.

5. Discussion section:
- In the last paragraph of HMI section, the authors mentioned "robot-friendly way". Why it's not "age-friendly way" or "care recipient-friendly way"?

References

1. Schüssler S, Zuschnegg J, Paletta L, Fellner M, et al.: Effects of a Humanoid Socially Assistive Robot Versus Tablet Training on Psychosocial and Physical Outcomes of Persons With Dementia: Protocol for a Mixed Methods Study.*JMIR Res Protoc*. 2020; **9** (2): e14927 PubMed Abstract | Publisher Full Text

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5. Yuan F, Anderson J, Wyatt T, Lopez R, et al.: Assessing the Acceptability of a Humanoid Robot for Alzheimer's Disease and Related Dementia Care Using an Online Survey. *International Journal of Social Robotics*. 2022; **14** (5): 1223-1237 Publisher Full Text

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
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Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Human-robot/computer interaction; human-centered AI; dementia care

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.