



User-Centered Design of Internet of Robotic Things (IoRT) for People Living with Dementia

Emmanuel Akinrintoyo^{1,4} · Virginia Ruiz Garate^{2,3} · Paul Bremner⁴

Accepted: 22 April 2025

© The Author(s), under exclusive licence to Springer Nature B.V. 2025

Abstract

As the population of persons living with dementia (PwDs) continues to rise, technological advancements offer an unprecedented opportunity to enhance their independence and quality of life while lowering the burden on the caregivers. Notably, the Internet of Things (IoT) has demonstrated significant assistive potential, yet it has some inherent limitations, such as a lack of physical embodiment and mobility capabilities. These are vital characteristics that robotics uniquely provide making it an ideal complement to IoT. However, the potential of dementia-specific applications that integrate the strengths of IoT and robotics remain largely underexplored in current research. Hence, this work presents a proof-of-concept Internet of Robotics Things (IoRT) system for PwDs based on participatory design sessions with dementia care professionals (DCPs). The system includes capabilities such as personalised reminders for drinking and medication-taking activities and memory exercises for cognitive stimulation. An initial evaluation of the system by DCPs was used to formulate further core design recommendations for an IoRT platform tailored for PwDs. This includes incorporating lucidity detection and a private cloud for data management.

Keywords Medication adherence · Internet of robotic things · Dementia · Reminder systems · HRI · Ambient assisted living · Robots for dementia

1 Introduction

There is a global demographic shift leading to a systemic rise in the older population and a decline in birth rate [1]. This is more paramount in Europe where its ageing population is backed by an increased life expectancy rate [2, 3] due to factors such as technological advancements, medical

breakthroughs, and greater access to quality healthcare [4, 5]. This ageing population presents a multifaceted problem to the societal structure with strains on the healthcare infrastructure and fewer people within the working-age bracket offering care provision services [6].

The COVID-19 pandemic exposed the staffing need whereby a great burden was placed on the care sector at an unprecedented rate beyond its capacity [7, 8]. Healthcare facilities such as care homes became incubators for the virus to thrive and wreak significant havoc. Deaths in care homes represented about 30% of all COVID-19-related deaths across 25 countries even though older people make up 1% of the global population [9]. This was a much lesser problem for seniors living in their homes because they could be isolated from others. These factors have heightened the need for independent living and increased healthcare staffing.

Previous research on independent living and age-friendly environments found that Ageing in Place (AiP) is a viable solution [10] which provides a strong sense of connectedness, satisfaction, reduced burden on care provision capacity and a significant reduction in the remarkable institutionalisation costs [11, 12]. Hence, most older people prefer it

✉ Emmanuel Akinrintoyo
e.akinrintoyo23@ic.ac.uk

Virginia Ruiz Garate
vruizg@mondragon.edu

Paul Bremner
paul2.bremner@uwe.ac.uk

¹ I-X and Department of Computing, Imperial College
London, London, UK

² Faculty of Engineering, Mondragon University, Mondragon,
Basque Country, Spain

³ Ikerbasque, Basque Foundation for Science, Bilbao, Spain

⁴ Bristol Robotics Lab, University of the West of England,
Bristol, UK

to institutionalised care. Yet, the care providers' shortage meant it was not fully adopted because the elderly typically require long-term medical support since ageing comes along with health challenges such as limited independence due to cognitive decline from illnesses [13–15].

Among the many challenges older adults face, dementia is one of the most prominent, impacting thinking, memory, and cognitive abilities that affect their daily living activities [16, 17]. Recent estimates indicate that 1 person develops dementia every 3 seconds globally [18] with the 55 million people living with it currently estimated to reach 139 million by 2050 globally¹ [12, 18].

Internet of Things (IoT) facilitates the independent living of persons living with dementia (PwDs) in the early stages, with Smart Homes being used for age-friendly environments [19]. However, it has some inherent limitations which have led researchers to combine its capabilities with robotics to form a paradigm called the Internet of Robotic Things (IoRT) [20–22]. IoRT is an emerging field being studied in simulated Smart Homes known as Ambient Assisted Living (AAL) [23, 24] facilities. AAL encompasses assisted living technologies that leverage ambient intelligence to help people live independently [6]. Yet, little focus has been put on their specific use for PwDs.

The lack of understanding of system requirements for IoRT design is one of the reasons for its lack of adoption in real-world settings [25]. This study identifies two primary types of end-users: individuals with dementia who directly benefit from the technology and caregivers who use the technology to support their professional responsibilities. This research primarily concentrated on caregivers. Hence, this research consulted with dementia care professionals (DCPs) to bridge this gap. This paper presents the design of an IoRT system for reminders for persons with dementia for an in-home deployment with cognitive exercise support. This involves the development of an IoRT platform for PwDs with capabilities to remind and assist them with daily living activities such as drinking, medication intake and memory exercises to aid their cognitive abilities.

Section 2 highlights prior work on reminder systems for activities such as medication intake due to the significant challenge of ensuring adherence. Section 3 presents the participatory design process involved in the system's development and evaluation. Participatory design was adopted to capture the experiences of DCPs in caring for PwDs to develop the design requirements of the IoRT system to increase its suitability for PwDs. This will serve as a vital groundwork that would feed into future work involving consultations with PwDs. The developed system in this work was used to produce use case examples for a focus

group evaluation. The system's usage helped to portray representative human-robot interactions while overcoming the abstractions of trivial and complex tasks [26] for DCPs to evaluate, as presented in Sect. 4. This was used to synthesise a set of design recommendations in Sect. 5 for designing such systems in the future.

2 Related Work

2.1 Reminder Systems

The advancement of technology has facilitated the development of active reminders involving the use of technology such as mobile applications [27–30]. However, seniors with dementia may not remember the steps needed to perform a task they are reminded to do by such mobile applications and devices [31]. Hence, robots can offer a significant advantage over mobile phones and tablets [32].

Unlike a robot, phones and tablet devices cannot navigate by themselves to a specific location or be operated without the help of a human [33]. A person would have to be in the same place or room where the device is located to receive a notification. Furthermore, mobile gadgets cannot track the presence of a user to know when to offer a reminder. They also offer limited support for medication adherence since taking medications involves physical and cognitive abilities [34].

Medication adherence measures how much patients comply with their medication intake as prescribed by a health-care professional [35, 36]. Its precise monitoring is a global healthcare challenge. Non-adherence includes overdosing, forgetting, and lack of compliance with schedules and prescribed doses [37, 38]. This situation is exacerbated by the cognitive limitations imposed by dementia [39] which can cause patients to confuse the names or the prescribed dosages between various medications [38]. In addition, older people typically take between 1 to 5 different scheduled medications daily together with over-the-counter pills [40]. Hence, medication errors account for up to 50% of errors in healthcare settings [40].

There are significant implications for regularly missing or taking the wrong doses because it can worsen health conditions or lead to further complications or death [41]. For instance, in the United States over 100,000 people die annually from non-adherence, with costs of over 100 billion dollars yearly [42]. These problems have fuelled the need for new solutions that can foster adherence.

Reminder applications on phones and tablets [43], telemedicine [44], electronic prescription refills [45], wearable devices [46], and pill dispensers [47] have previously been explored for aiding medication adherence. However such

¹ <https://http://www.who.int/news-room/fact-sheets/detail/dementia>

computerised solutions have no embodiment or physical appearance that can aid adherence compared to a robotics solution. Hence, the potential of robotics for medication adherence has been explored by research such as [48–50]. However, the systems were largely limited by the lack of sufficient vision algorithms to aid the activity and had little or no capability to identify cases of overdose or underdose of medications.

Furthermore, some of the previous systems did not follow a participatory design process, thus creating a gap, such that their capabilities did not match up well with real-world requirements. Wearables were also employed, thus introducing a limitation because PwDs can lose or forget to put on such devices. These limitations are addressed in this work to construct a reminder system with a robot that utilises effective vision algorithms to support adherence with support for identifying overdosing or underdosing and without wearables.

2.2 Robotics for Dementia Care

Robotics has been used for elderly care with intelligent assistive technology to compensate for the limitations faced by older people [51–54]. Table 1 highlights some previous research areas on robots for PwDs. This includes robots that provide (i) companionship and well-being to combat loneliness and social isolation [55], (ii) cognitive support to compensate for cognitive deficits of dementia [56], (iii) physical exercise for performing therapeutic exercises [51], and (iv) robots that alleviate behavioral and psychological deficits (BPD) in PwD [53].

Previous work on robotics development on reminder systems focused mainly on the general older adult population with little dementia focus [73]. Rantanen et al. [73] explored a static robotic device for medication adherence suitable for dispensing medication as needed. The system had limited capabilities to aid other activities such as drinking and eating. Additionally, the system assumes that retrieval of the medication sachet implies the medication was taken. It does not directly verify whether the patient consumes the medication or completes the activity, which is a limitation shared with other systems [74, 75].

Robots that provide stepwise prompts for PwDs are rare [25]. The few existing systems lack comprehensive interactive capabilities to guide users through each step of an

activity in a detailed manner, as is particularly necessary for PwDs. Previous work by Khosla et al. [76] developed a robot that could provide reminders for social events, birthdays, and drinking water (with no assistance). This had a similar functionality of providing simple prompts to persons with cognitive limitations to other similar work [77, 78]. The importance of stepwise prompting for PwDs was highlighted by Wang et al. [25] with a teleoperated robot. They found that PwDs need stepwise prompting to complete complex tasks such as tea-making. Other complex instrumental activities of daily living for PwDs include paying bills, doing laundry, preparing meals and taking medications [25]. This work leverages an autonomous robot to support drinking (including tea preparation) and medication-taking activities with stepwise assistance for PwDs.

2.3 Ambient Assisted Living (AAL)

Robotics capabilities are being explored with IoT to develop AAL testbeds which are vital for experimentation. Early AAL infrastructures include Aware Home [79, 80] and I-Living [81]. These assisted living environments included capabilities for monitoring and reminding while serving as tools for investigating user's acceptance to guide the development of AALs. This has led to the emergence of modern AAL infrastructures.

Modern AAL infrastructures include Robotic Assisted Living Tested (RALT) [82] at Edinburgh Centre for Robotics in Scotland. RALT, including other testbeds such as HomeLab² at Sheffield University, generally focus on older people with aims that include helping the elderly with activities of daily living but with little dementia-specific use cases. Prior research has investigated use cases for the general elderly population, which are often not well-aligned with the specific needs of the dementia population. Thus, in this work, an IoRT-based AAL environment was constructed with specific use cases for PwDs to support their daily living activities.

2.4 Participatory Design for Older Adults

There is a significant gap in technology adoption for care provision mainly due to the isolation of technological development from its target audience [83]. Researchers and developers built their technology based on their stereotypes and biases about the needs of the elderly population without concrete engagement with them or their caregivers to understand the specific needs they should address and the design features necessary to incorporate [83]. This led to

Table 1 An overview of previous literature on robotics for older persons with dementia

Application Field	Relevant Research
Companionship and well-being	[57–60]
Cognitive support	[61–64]
Physical exercise or therapy	[65–68]
BPD alleviation	[69–72]

² <https://catch.sites.sheffield.ac.uk/about>

adopting techniques such as co-design [26, 83] and user-centered design [84].

Participatory and user-centered design have been utilised for understanding the needs of PwDs [85, 86] and developing solutions such as mobile and web applications [87–89], Smart Homes [90, 91], AAL environment [92] and robotics [83, 93, 94]. Since a robot can complement and aid caregivers in the care delivery of PwDs, their experiences and knowledge are of the utmost importance because they engage with PwDs daily. Hence, unlike previous work, this work considers caregivers in developing an IoRT platform for an in-home reminder system geared towards independent living, integrating personalisation and cognitive stimulation exercises using a large language model.

By first engaging with care professionals a higher level of development could be realised to meet the needs of PwDs, such that a more refined system could be presented to them to get their input. Also, DCPs will highlight key features needed by PwDs, which PwDs will evaluate in a follow-up study to get their input on features suggested by the DCPs. Previous work such as [92] has co-designed with informal caregivers for developing an AAL environment. However, this work seeks to contribute to existing knowledge by adopting a participatory design with formal caregivers to develop an IoRT-based AAL environment for PwDs. Unlike most previous work, this work also considers a real system for evaluation by the stakeholders.

3 Method

The participatory design process adopted involved an initial consultation with DCPs to identify the core needs of PwDs (the most notable of which is the need for regular reminders) and suitable design features of an IoRT platform. Example applications and scenarios were then recorded to demonstrate the capabilities of a working system to base the focus group discussion with DCPs on a real system to ascertain its strengths, weaknesses and suitability for aiding PwDs in their daily living activities. A real system implementation was beneficial for aiding the discussion on the details of an

activity, understanding how such a system works in practice, and the viability of DCP suggestions.

3.1 Initial Consultation

An initial consultation was held with four DCPs. This consists of three females and 1 male (details are provided from DCP1–4 in Table 2). They have years of experience ranging from three to over 10 years. The consultation was held to discuss the challenges faced by PwDs in their daily living activities, including those faced by DCPs in their work to support PwDs daily. The discussion helped to identify the core activities and functionalities for which an IoRT can be used to provide support. The core activities identified were drinking, eating, and medication intake as supported by existing literature such as [95–97]. This is because the water-food-medication relationship is crucial since the digestive system connects them, and medications are typically taken before or after a meal, and the omission of either can hinder proper treatment [95]. This work focuses on drinking and medication activity. A high-level description is provided in the next subsection. It is anticipated that a similar approach could be applied to the eating activity [95], such as when using a microwave or oven. Similar sensors and Naomarkers can be attached to them while leveraging Pepper's existing navigation capabilities to the kitchen area.

3.2 IoRT System Design

The AAL studio in Fig. 1 was used to construct an IoRT platform equipped with sensors and IoT devices placed at strategic locations in the living area and kitchen. This includes items such as the fridge, oven and medication cabinet. Aldebaran's Pepper robot³ was used as an interactive agent facilitated by the data from the smart devices. Contact sensors were used to detect their openings and closings to trigger interactions.

Home Assistant⁴ was used as the central hub for the sensors and IoT devices. Home Assistant was hosted on a Raspberry Pi [98], thus providing a cost-effective solution. The sensors used ZigBee and Z-Wave communication protocols to communicate with the Home Assistant hub. Hence, ZigBee and Z-Wave USB (Universal Serial Bus) dongles were connected to the Raspberry Pi 4 to interface with ZigBee and Z-Wave sensor devices. Additionally, automation scripts on Home Assistant were used to track the status of the sensors and devices to develop interactions with Pepper, the socially assistive robot.

Table 2 Overview of Dementia Care Professionals for the Focus Group Study. This includes an RTL (Research and tech lead), a RIO (research and innovation officer), a DSL (Dementia support lead), and three DSS (Dementia support staff), their roles, experience and ethnicity

DCPs	Gender	Role	Experience	Ethnicity
DCP1	F	RTL	10+ years	Irish
DCP2	M	RIO	3+ years	English
DCP3	F	DSL	10+ years	English
DCP4	F	DSS	10+ years	English
DCP5	F	DSS	5+ years	English
DCP6	F	DSS	5+ years	Asian

³ <https://http://www.aldebaran.com/en/pepper>

⁴ <https://http://www.home-assistant.io/>



Fig. 1 The AAL studio consists of a living and kitchen area equipped with contact sensors and markers on items such as the medication cabinet and fridge

A smart plug was integrated via its Python API (Application Programming Interface) for remote controlling and monitoring. The functionalities of the plug allow for various interactions to be developed with Pepper to assist a user in the studio. For instance, the state of the plug can be tracked continuously such that the robot can know when a kettle has been triggered by a user. Likewise, the robot can receive commands to remotely turn the plug on or off to assist a PwD with activities such as tea preparation.

Furthermore, a log of activities within the house is recorded to complement the information obtained from the user during the registration phase for personalisation such that Pepper could answer specific questions such as “Have I had a drink today?”, and “Have I taken my medications today?”. Personalisation is aided by face recognition and a database of personal information. Here, GPT (Generative Pre-trained Transformer)-3.5⁵ was used to infer the information from the logs hence, functionalities such as playing a user’s favourite song could be developed using Pepper’s tablet.

A 2-dimensional map of the studio was constructed to help Pepper navigate within the house to aid its user. Hence, it could point at items or move to specific locations to aid an activity through verification and instructions. Two reminder types were considered: custom reminders at specific times and reminders based on triggers such as cabinet opening or kettle toggling by a user. The features of the AAL system are according to the initial design requirements.

3.2.1 Vision

Pepper was equipped with vision capabilities for human detection, face detection and recognition. The human detection algorithm ensures it can recognise the humans within the living area and kitchen from its base in the studio. The facial detection and recognition help to register a user on the system to aid future interactions. Thus, the need for PwDs

to wear wearables is eliminated. Additionally, landmarks (naomarks⁶) were also utilised for identifying items such as the fridge and medication cabinet. Naomarkers can be seen on the fridge and behind the medication cabinet in Fig. 1. Pepper could identify a specific item in the AAL based on the marker it had.

YOLOv5 models [99, 100] were also trained to recognise medication packs and pills. Four medication packs (Paracetamol, Lemsip, Ibuprofen, and Strepsils) were used to train the model which achieved a precision of 97%, recall of 97.1% and mAP (mean average precision) of 99.5%. Sample pill colours (blue, green, yellow, orange and black) were represented using *m&m's* to train a model which achieved a precision of 94.6%, recall of 91.3% and mAP of 99.5%. The medication packs were also equipped with iBeacon tags for identification to validate the predictions of the vision algorithm. When there is a discrepancy between the vision algorithm and the information obtained from the tag reader, Pepper would promptly flag this to the care assistant for further consideration. Pepper would gently remind the user to avoid taking the medication at this time.

3.2.2 Speech Capabilities

Pepper’s internal speech engine was aided by Google’s speech API for speech-to-text conversion and complemented by GPT-3.5, which was used for speech verification to check the grammatical correctness of transcribed speech. GPT-3.5’s personal assistant persona was also used to support tasks such as obtaining steps for tea preparation with capabilities to answer clarifying questions and for memory exercises, which can aid the cognitive abilities of PwDs. These functionalities are vital for the example applications presented in the next section.

⁵ <https://platform.openai.com/docs/models/overview>

⁶ <http://doc.aldebaran.com/2-5/naoqi/vision/allandmarkdetection.html>

3.3 IoRT Example Applications

Four example use cases of the IoRT platform for supporting PwDs were developed and recorded for evaluation in the focus group described in subsection 3.4. They were designed to showcase system capabilities and foster discussion of use cases of the IoRT development environment. Once a user is registered on the system, they can have personalised interactions, including memory exercises and reminders for drinking and medication activities.

3.3.1 User Registration

For the system to be personalised for a specific user, it must first register the user's face and obtain some personal details. Here, the interaction begins once Pepper detects a person's face. It introduces itself and then requests the user's name to be used as a label for their image, which is stored locally on the system. After the facial registration, it informs the user that it would remember their face before asking for personal details such as their favourite meal, drink, song, hobby, an interesting place they have travelled to, and what they are most passionate about. These questions were suggested by DCPs. The only modification was that instead of inquiring about their past occupation, it prompts them to share what they are most passionate about for a more open-ended response. This reduces the cognitive load on PwDs on having to remember specific details of the past. The user is notified when the registration is completed. The video can be viewed at <https://youtu.be/QpRNjqzRxWI>.

3.3.2 Personalisation

The purpose of this demonstration is to show that Pepper can provide personalised interactions for a registered user including answering questions regarding their daily activities. This was achieved by combining the user's data with their activity log recorded in the studio. Here, the user initiates the conversation before Pepper performs a facial recognition to identify the user before asking about their well-being. It then prompts the user to see if they have a question they want to ask. The user then asks "Have I taken my medication today?". The robot provides a positive response since it has recorded a prior medication activity. This is followed by "When should I take my next medication?" for which a time of day (2 pm) is provided.

Pepper then offers to engage in a memory recall exercise powered by GPT-3.5 with three options (word recall, story recall and mind mapping) suggested from which word recall is chosen. It begins by telling the user a word and asking him to think of any word that comes to mind. The response Pepper receives is "I don't know", to which it responds with

a positive affirmation before the second attempt. It intends to continue before the user suggests that he would prefer a different exercise. Pepper then requests for the preferred exercise to which the user responds by asking for a list of words. A list of 10 words is provided, from which the user recalls two. The robot then gives a positive affirmation before it seeks to know if the user wants to continue. The demonstration ends with the user saying "no". The video can be viewed at <https://youtu.be/HFy3a4TKFHs>.

3.3.3 Drink Reminder

This example application highlights Pepper's capabilities to aid drinking activity with the fridge or kettle and how it can navigate within the home to support such activity. Here, it utilises the activity log to detect if either has been used during the day. Thus, it runs its human detection and facial recognition algorithms at a set time to identify the user. When the user is detected, it reminds him that he is yet to have a drink before asking what he wants to have.

If the user decides to have a cup of tea, Pepper will offer to turn the kettle on. If the user agrees, then the kettle will be turned on, and the user will be notified once it boils. Pepper would offer to follow the user to the kitchen to get the kettle. When it arrives at the kitchen, it recites the steps necessary for tea preparation using GPT-3.5. The user is then asked if he has any questions, to which he asks "how much milk should I add". It verifies if the user is drinking the tea to update the log. The drink reminder ends with Pepper asking if it should play his favourite song while having the drink. The video can be viewed at <https://youtu.be/GZLEnQ5IH-Y>.

3.3.4 Medication Reminder

This demonstration aims to portray a robotics solution for aiding medication intake through vision algorithms and verifications to ensure medication adherence. Pepper runs its detection algorithm to detect the user at a set time before offering to guide him to where the medication cabinet is located, after which it points to the cabinet. The user is then asked to open the cabinet to pick the medication packs while a visual reminder of a person with pills on their palm and a glass of water is shown on Pepper's tablet.

The medications to be taken are recited with instructions for the user to show each pack to its camera for verification, with corrections made when a wrong pack is chosen. The user is then asked to take the pills from the correct packs to show them for verification to detect a possible underdose or overdose. To end the activity, the user is asked if he took all the pills and if they were taken with water to log it with the time, date and an image of the pills taken to be sent as a file in an email attachment to the carer. The flowchart of the

medication reminder is presented in Fig. 2. The video can be viewed at <https://youtu.be/wCdw0RyXqpc>.

3.4 Focus Group

Ethics approval was obtained by the university’s ethics committee for the study (REC REF No: FET-2122-153). The study was conducted following ethical standards, and consent was obtained from all participants. A 2-hour focus group study was held with DCPs on Microsoft Teams to evaluate our proposed IoRT application and to understand how such a system could be developed to meet the needs of DCPs. The focus group aimed to review the IoRT system and hence to obtain design guidelines for developing an AAL environment for PwDs. The session was conducted using Miro⁷—a remote board for collaboration with each segment consisting of a question and whiteboard area for participants to add their opinions and suggestions using sticky notes for the group to discuss. The focus group was divided into 3 sections which included:

1. General questions on technology use, such as robotics for assisting PwDs in their daily living activities (35 minutes)
2. A review of each example demonstration (50 minutes)
3. A review of the overall system (35 minutes)

The first session consisted of 8 open-ended questions that sought to ascertain the core daily activities in which

technology can be utilised, limitations to the usage and comparisons between existing solutions. In the second session, each example application was shown and followed by a review with predefined questions to ascertain its usefulness and to obtain suggestions for improvements. The third session involved reviews of the overall system to identify its strengths, limitations, and suitability for aiding PwDs.

3.4.1 Participants

Six DCPs were recruited for the focus group. The DCPs included 5 female participants and 1 male, consisting of a research and technology lead, a research and innovation (R & I) officer, 1 care support lead and 3 care support staff. The DCPs had some technical knowledge because there is an emphasis on using IoT devices for supporting the PwDs with daily living activities in their charitable independent living facility. The research and technology lead also assists with dementia care within the same organisation with a specialist knowledge of how technological devices are used to support the daily needs of PwDs.

The participants support PwDs daily and had at least 3 years of experience in dementia care, as highlighted in Table 2. The caregivers work in Western Europe, and their experiences are reflective of formal caregivers.

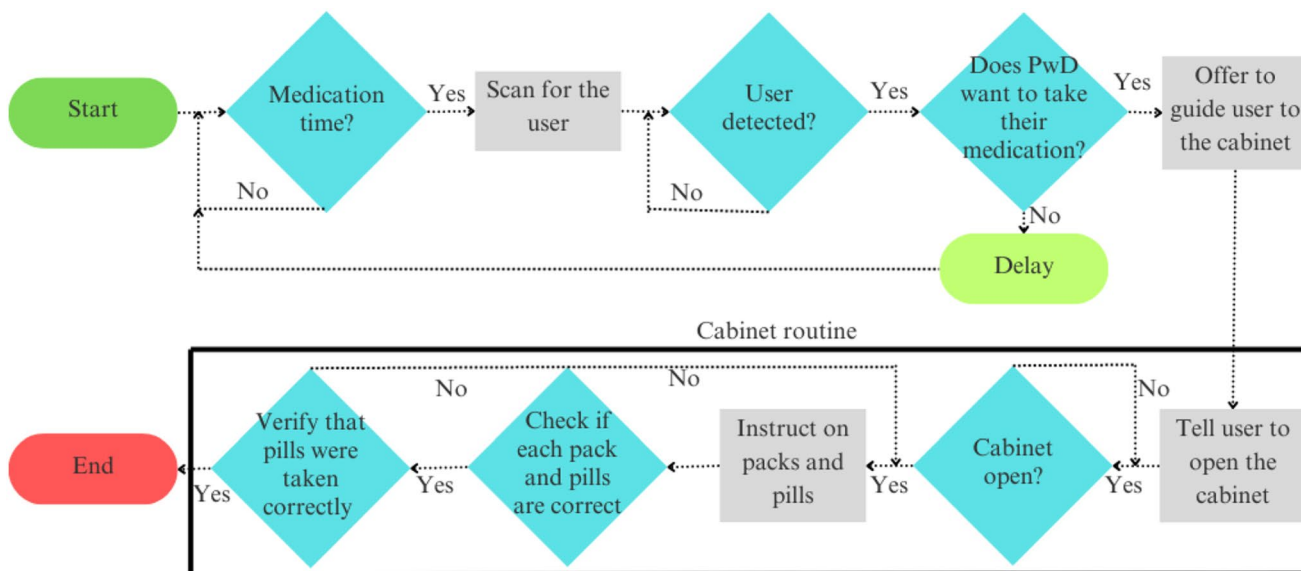


Fig. 2 The flowchart of the medication reminder commences with Pepper checking if it is time for the user to take their medication. It ends with a verification that all the pills were taken correctly

⁷ https://miro.com/app/board/uXjVMhPh0EQ=?share_link_id=993898008254

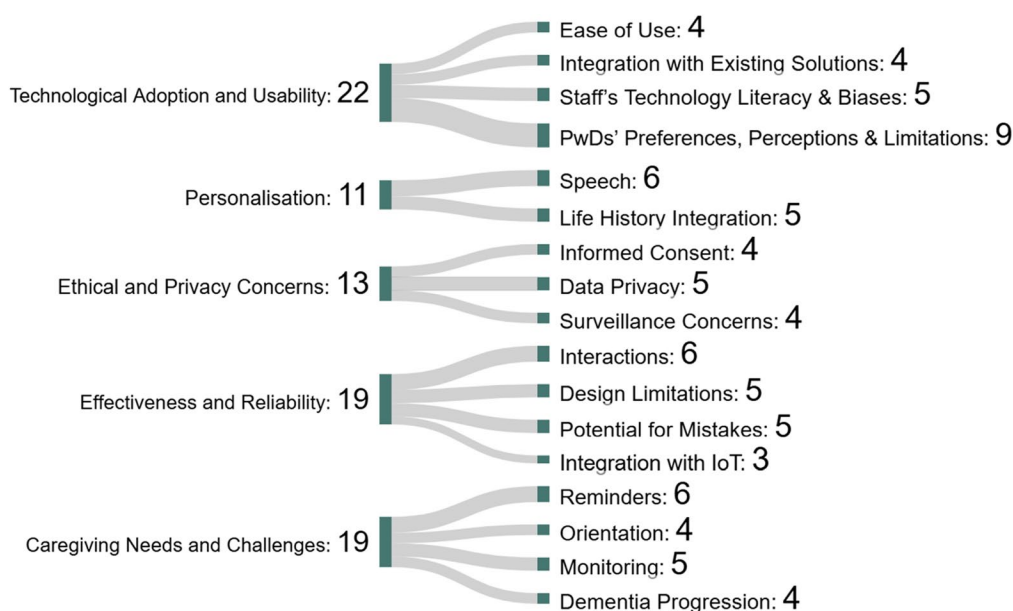


Fig. 3 The five themes and their sub-themes obtained from the thematic analysis of the focus group with six DCPs are presented in this figure

4 Results

The focus group discussions were transcribed to be interpreted along with the discussion points of the Miro board using inductive thematic analysis [101], one of the most used for qualitative data, as it ensures the rigour and trustworthiness of the findings. Thematic analysis was used to identify the core themes to ensure that the results are credible, transferable and reliable. The themes are presented in Fig. 3. The coding process involved sorting the transcribed responses and dialogues into categories. Quotations from DCPs are used to corroborate each thematic code as presented below with the themes:

4.1 Theme 1: Technological Adoption and Usability

An important theme emerged regarding the usability and adoption of technology, which can be hindered by factors such as the biases and perceptions of its target users.

4.1.1 Ease of Use

DCPs identified the ease of use of technology as a major factor determining its adoption. Robotic technology must be user-friendly so people with no technical knowledge can sufficiently use it. DCPs cited that an important question that should be answered for any technology is “how easy is it to access for someone with no technical knowledge?”. They also highlighted poor usability as the reason for abandoning some technology especially those with difficult mechanisms

for accessing the data collected during the day on activities in a house.

(DCP1): “The dashboards for data storage and accessibility were not clear for some technologies.”

(DCP5): “Some residents (PwDs) are unable to use phones so it needs to be user-friendly.”

The DCPs then noted that there is a high likelihood of usage for a robot if the contribution from staff for its operation is as minimal as possible. Staff will be more encouraged to adopt it when they know they have to contribute little to its daily usage.

(DCP1): “The least amount of effort required from staff, the better.”

4.1.2 Integration with Existing Solutions

DCPs suggested that the assistive robot should be able to connect with some of the existing technology and solutions used by PwDs such as pillboxes or blister packs for medications. For instance, a “pharmacy can have the meds in a box where it is ready without any packaging” which was stressed further by DCP1.

(DCP1): “Would it work with a blister pack where the pills are already out of the box.”

4.1.3 Staff's Technology Literacy and Biases

Technology use depends on biases and literacy skills of its potential users. As humans, the staff have inherent biases and beliefs which can hinder their adoption of such technology. The acceptance of staff must complement that of PwDs for a successful adoption of a technology.

(DCP1): *"Staff may think devices are going to replace them."*

DCPs suggested that a lack of sufficient technology literacy could hinder the use of robotics as DCP1 pointed out that "staff literacy is important in deciding which technology is adopted". However, they discussed having some form of training, and ongoing support.

(DCP4): *"Most staff are not up to date with all the tech so it must be very easy to access."*

4.1.4 PwDs' Preferences, Perceptions and Limitations

PwDs are the target users of robotics technology thus, their perception of it is critical to its adoption. DCPs stated that some PwDs have to overcome the fear of technology since they are often unfamiliar with it. This can include helping them to overcome their paranoia because they may be "worried that it is recording them". Thus, a case-by-case assessment for the adoption of robotics is necessary.

(DCP6): *"(It is) good to hear from someone with dementia and their family members when it comes to technology use."*

The cognitive limitations of PwDs are another potential barrier to using robotics to support them. PwDs may not understand the concept of an intelligent robot or its limitations, such that they treat it as a human. Moreover, they may forget why it is stationed in their home thus they may "have a shock when they see or hear it".

(DCP3): *"They may not understand why it is there. The robot must be able to explain what its role is and why it is stationed in their home."*

4.2 Theme 2: Personalisation

A common theme in the discussion was personalisation, especially in terms of how a social robot interacts with the service users while having sufficient knowledge about them to develop and maintain a connection with them.

4.2.1 Speech

The speech functionality of a robot was identified as a core element in its interaction with PwDs. Ideally, the assistive robot should be capable of speaking multiple languages, and voices for PwDs to choose with accents that match their cultural backgrounds. DCPs suggested that the robot must be able to engage in "short, simple conversations" with no long sentences that could be difficult for PwDs to understand.

(DCP1): *"One patient could not understand the female voice on Alexa but could hear the male's voice."*

DCPs also discussed the use of childlike voices with some arguing that "it does not sound scary or intimidating" however, others noted that it may trigger some emotions. Hence, they concluded that it would depend on each user's preference. Thus, multiple voices should be played at the user registration phase for PwDs to choose their preferences.

4.2.2 Life History Integration

The DCPs considered personalisation as a major design functionality in the utilisation of robotics for care provision as observed in EX2. DCPs agree that it is essential an assistive robot is equipped with sufficient knowledge about its user. This can include questions about their physical abilities and limitations to help cater for their needs and to aid the generation of custom interactions.

(DCP3): *"Is there anything you struggle with or find difficult around the home? (Pepper) could use this to develop personalised routines and care."*

DCPs also suggested that the robot must have some information about the family of a person living with dementia and their prior working history to help engage with them better and develop relevant interactions.

(DCP4): *"It should ask about their family and what they worked as to have a more fluid conversation especially if the robot can recognise the person's face to make the conversation more real."*

In addition, the DCPs noted that the daily activities the assistive robot knows should be complemented by other information such as important dates (birthdays, anniversaries, appointments), the preferred name they want the robot to call them and the activities they do at specific times.

4.3 Theme 3: Ethical and Privacy Concerns

Various ethical issues were identified regarding using robotics for the activities that a robot can help with. These issues were highlighted with DCPs noting how a robot's usage may interfere with privacy and consent.

4.3.1 Informed Consent

Despite the potential for social robots to support the independence of PwDs, the consent of PwDs to have them deployed in their homes is of the utmost importance. Therefore, DCPs deliberated whether PwDs would have the capacity to consent to use a robot in their homes to ensure that the risks and benefits are well understood.

(DCP2): *“Can the person give their consent and is their consent fully informed?”*

4.3.2 Data Privacy

Besides consent, DCPs discussed data privacy as an important consideration. The data collection of the robot through its microphone, cameras and interactions with a user including the personal details to which it has access was of concern to the DCPs to avoid a potential exploitation or breach of privacy.

(DCP6): *“Who can access the data collected by the robot?”*

4.3.3 Surveillance Concerns

Social robots are typically equipped with cameras essential for functionalities such as perception, facial recognition, navigation, and activity recognition. However, some of the DCPs were more concerned about the monitoring aspect which PwDs may find uncomfortable when a social robot is deployed in their home.

(DCP1): *“The use of cameras is a bad idea because that is the first thing PwDs and their family are concerned about—“is it recording me?” ... but I can see why cameras are needed.”*

4.4 Theme 4: Effectiveness and Reliability

Robotics technology must not only fulfil their intended functions effectively but must also perform reliably for continuous usage.

4.4.1 Interactions

Clear instructions must be provided for a task through “step-by-step instructions as it notices each completed step” with visuals to aid cognitive abilities as in *EX3* and *EX4*. For instance, it should verify if a user has poured water into a cup before suggesting that a teabag should be added. Each completed activity should then be followed by positive reinforcements to serve as an encouragement to continue.

Likewise, the robot should know the location of items such as tea bags, cups and spoons to guide PwDs. The importance of an activity for which a reminder is being provided must also be known by the robot. For instance, it should be able to tell a user why they should take their medication and what the medication is for as shown in *EX4*.

In addition, DCPs agreed that the instructions must not be too fast to ensure a user can keep up with it and a few open-ended questions should be asked while completing a task. Moreover, options should be provided to aid PwDs. Flexibility should also be provided to ensure users can change activities when needed such as in *EX2*.

(DCP2): *“Very polite and non-forceful interactions, people want to feel they still have autonomy. Posing things as questions instead of instructions is great.”*

(DCP6): *“For people living with dementia, long and complex questions might confuse them. If Pepper's questions can be short and simple, I think users will get on better with her.”*

4.4.2 Design Limitations

While a robot was highlighted as a vital tool that could complement care delivery, some limitations to its usage were also highlighted by DCPs. The key limitations include the lack of verbal or visual cues (such as nods) that humans give during a conversation to verify they are listening to the person they are interacting with.

(DCP3): *“Latency time between answers—people may think that the robot did not hear them and repeat themselves.”*

Likewise, the verification of multiple items introduces a delay that PwDs may find unappealing because of “how long it takes to verify each medication pack” (DCP5) such as in *EX4*.

4.4.3 Potential for Mistakes

While robotics can be a vital tool for helping the elderly, there is also a potential for it to make mistakes. Its vision

algorithms can be prone to some errors such as when assisting with tasks or activities.

(DCP2): *“What if the robot makes a mistake? If it makes the wrong medication prediction, who is to be blamed?”*

4.4.4 Integration with IoT

DCPs discussed some of the key limitations to the use of IoT devices for care. The factors noted include dependence on reliable and always available Wi-Fi connectivity, and lack of knowledge regarding their value, durability, and battery life.

(DCP1): *“Wi-Fi connectivity can be a challenge for connecting all the different devices. Things can get disconnected which would not be good if it was a person’s medication reminder.”*

4.5 Theme 5: Caregiving Needs and Challenges

A common theme found in the discussions was the needs of PwDs and how technology adoption can aid their caregivers in helping to meet such needs.

4.5.1 Reminders

A reminder system was identified as a crucial tool for the daily living of PwDs as portrayed by the example application 3 (EX3) and EX4. DCPs stated that for instance, the medication reminder can assist their work significantly, especially with the robot’s verification system that includes a reminder of which medications to take and how many pills from each pack. They emphasised that the most common approach currently is that “staff reminds them through calls” because medication error is very common with dementia, (PwDs) often overdose due to forgetting they have already taken or don’t take at all. However, technology can be leveraged too.

(DCP6): *“It depends on the stage of the dementia. Early-stage dementia can cope with a pill box.”*

The robot’s ability to detect a mistake was highlighted as being crucial, in that it would give “staff and family the confidence to trust it”. A DCP summarised the necessary features as “interactions, politeness, reminders, monitoring, verifications, and instructions” (DCP5).

4.5.2 Orientation

Daytime orientation was noted as vital for PwDs to conduct their activities of daily living as required to ensure they are synchronised with the time of day.

(DCP3): *“In the morning they may not be aware it is morning or evening or night. They might have an afternoon nap and not know what time of the day it is. This can cause them distress so they need to be told the time.”*

The provision of memory exercises was noted as an important feature that could potentially help PwDs regain some of their cognitive abilities for better orientation.

(DCP6): *“The activities element e.g. word recall was the most useful.”*

4.5.3 Monitoring

Activity monitoring was identified as a core design feature that would help DCPs in their work. They suggested it would help them to stay rest assured that PwDs are being looked after even though they are unable to provide 24/7 monitoring.

(DCP6): *“I liked how Pepper will keep track on what the individual is drinking and eating, this is so important.”*

DCPs also proposed the development of novel technology that could assist the robot in its monitoring tasks such as in EX3. For example, DCP2 suggested a smart cup that can report to the robot if it has been used in a day and if the drink or water poured into it has been drunk. Likewise, a “fitbit-type” device was also suggested to monitor hydration levels.

(DCP2): *“A smart cup that can tell the robot if a drink has been finished or a plate for meals that can do the same.”*

Since there are existing services available for supporting PwDs such as those in independent living facilities, it is imperative that a robot can have connections to them. This can include the pharmacy for restocking medications or first aid services for when a fall has been detected.

(DCP2): *“It should contact the staff if there is no response from the user; maybe he or she has fallen.”*

4.5.4 Dementia Progression

The needs of PwDs change over time due to the progression of the illness. Hence, the robot’s functionalities should

adapt to the variations and changes in the cognitive capabilities of its users. DCPs highlighted that it can also help them decide as the level of independence of a service user wanes.

(DCP1): “(Pepper) can be good for spotting when someone is quite far down the road with dementia?”

5 Discussion

Based on the evaluation of the developed IoRT platform, the following design recommendations are proposed for developing an IoRT system for supporting PwDs to live independently.

5.1 Lucidity Detection Mechanisms

The development of a robotics solution for PwDs must integrate mechanisms for adjusting interactions based on the lucidity and emotional state of the service users. The robot’s interaction must not cause distress to its users, by avoiding shock or confusion. Hence, it must be able to detect when its user is disorientated such that it can stop interactions that rely on their orientation to engage except those intended to alleviate their disorientation.

5.2 Private Cloud Adoption

The findings showed that a privacy-by-design approach will aid the adoption of robotics technology. Hence, the adoption of a private cloud is proposed to eliminate the potential for privacy violations and prevent unauthorised access to the data collected by an in-home robot. This can help to increase the trust service users have in the technology.

5.3 Cognitive Stimulation

The caregiving needs and challenges of caregivers highlighted the need for cognitive stimulation. Cognitive stimulation would help to reduce the disorientation that dementia can impose on PwDs while helping to ensure they become more synchronised with the reminders they receive. This highlights the benefits of memory games and therapies such as cognitive stimulation therapy which has been explored with a robot [102].

5.4 Care Staff Influence Adoption

A key finding in this work is that the perceptions and biases of care staff strongly influence whether a technological solution is adopted by PwDs. While the involvement of PwDs in participatory design is essential for designing personalised

technology for them, the biases of DCPs can limit this regardless since they must help operate and maintain the devices. It must thus be ensured that the DCPs find the technologies to be implemented intuitive and easy to use. Therefore, the involvement of care staff in the technology design is of utmost importance to ensure its adoption by PwDs.

5.5 Personalised Communication Style

The communication style of a robot is an essential design consideration to ensure effective human interaction with PwDs in line with the findings of previous studies such as [93]. As the DCPs suggested, this can include the speech pace, style and accent as vital considerations to ensure that guidance and instructions the robot offers are coherently communicated to the service users. For instance, service users can be more endeared to a robot that uses their local accent with slang. There is also a need to ensure that a robot can communicate its intended purpose and use in the home of a person living with dementia.

5.6 the User Is in Control

While a robot can offer sufficient help with supporting PwDs, users should not be made to feel they are being controlled by it. Instead, an assistive robot should operate in a manner that makes its user confident that he or she can make their own decisions without being mandated to do otherwise. Hence, interactions should lean more towards the use of suggestions or guides.

5.7 Plug and Play Design

The findings from the focus group revealed that technology usage and adoption strongly correlate to the level of ease of use and accessibility. People are more likely to use a robot if they need to contribute little to its operation that is, a “plug and play” type of device is more likely to find use. Therefore, a robotics solution must be simple with little human involvement from staff or PwDs. Likewise, robotics developers must decrease the likelihood of error or malfunction significantly in the operations to help build and maintain users’ trust.

5.8 Guide for Non-Technical Users

The technical ability of the end users, including the care professionals and informal caregivers, largely differ. Thus, the adoption of robotics technology can be aided by the provision of guides, tutorials and troubleshooting manuals to adequately cater for the initial barriers that such groups may face. Furthermore, it is important to inform the users that

the robot is not replacing human interactions but complement them.

6 Future Work and Limitations

This work demonstrated the effectiveness of a social robot in navigating within a living space to support PwDs with activities such as drinking and medication intake. Unlike most previous work [76–78], stepwise instructions were provided to support each activity. This is vital for tasks such as medication intake to ensure adherence. The solution includes a personalised interaction that provides reminders for an activity with corresponding verifications to determine if the user completed it. This differs from previous solutions that explored using basic prompts without verification [73–75].

While the activity verification relies on a PwD's verbal response, future work can leverage activity recognition using skeletal data to detect the activity [103]. Activity recognition can also be used to guide each step of an activity such that the instruction for the next step is provided when the current step is detected as complete. Moreover, further work can include other activities such as eating.

A limitation of the work is that the findings are only representative of DCPs, which additionally shows a strong gender bias in line with the skewed representation in the field, and may not be representative of the views of PwDs or all DCPs.⁸ The reasoning behind this choice is so that system designs suggested by DCPs can be incorporated for evaluation by PwDs in future studies. Indeed, in the future, the system will be developed further, and the participatory design process will be extended to include PwDs for the design of IoRT platforms for assisted living.

7 Conclusion

This work presents the development of an IoRT platform to aid PwDs in their daily activities by providing timely reminders for drinking and medication intake. Support for medication adherence was integrated into the system with personalisation at its core. Example use cases were then developed to portray the capabilities of the system to form part of a focus group with dementia professionals. The findings of the focus group were then used to produce a set of design recommendations for developing such systems in the future. The findings also validate some design recommendations described in previous robotics research. These findings will lay the groundwork for future work involving

consultations with PwDs and will thus highlight corresponding similarities and differences in the design recommendations between caregivers and care receivers.

Data Availability All the data for this research are available upon request.

Declarations

Conflict of Interest We declare that all authors do not have any conflict of interest/competing interests.

References

1. Bloom DE, Luca DL (2016) The global demography of aging: facts, explanations, future. *Handbook of the economics of population aging* 1:3–56
2. Barber R et al. (2022) A multirobot system in an assisted home environment to support the elderly in their daily lives. *Sensors* 22:7983
3. Cooper S, Ros R (2022) Towards the deployment of a social robot at an elderly day care facility. *Int Conf on Soc Robots* 277–287.
4. Kirkwood TB (2017) Why and how are we living longer? *Exp Physiol* 102:1067–1074
5. Woessner MN et al. (2021) The evolution of technology and physical inactivity: the good, the bad, and the way forward. *Front in Public Health* 9:655491
6. Rashidi P, Mihailidis A (2012) A survey on ambient-assisted living tools for older adults. *IEEE J Biomed Health Inform* 17:579–590
7. Watterson A (2020) COVID-19 in the UK and occupational health and safety: predictable not inevitable failures by government, and trade union and nongovernmental organization responses. *New Solut* 30:86–94
8. Parzonka K, Ndayishimiye C, Domagała A (2023) Methods and tools used to estimate the shortages of medical staff in European countries—scoping review. *Int J Environ Res Public Health* 20:2945
9. Mahase E (2021) Covid-19: neglect was one of biggest killers in care homes during pandemic, report finds. *Bmj*
10. Sixsmith A, Sixsmith J (2008) Ageing in place in the United Kingdom. *Ageing Int* 32:219–235
11. Wilmoth JM (2000) Unbalanced social exchanges and living arrangement transitions among older adults. *Gerontologist* 40:64–74
12. Ienca M, Jotterand F, Vică C, Elger B (2016) Social and assistive robotics in dementia care: ethical recommendations for research and practice. *Int J Soc Robot* 8:565–573
13. Chang AY, Skirbekk VF, Tyrovolas S, Kassebaum NJ, Dieleman JL (2019) Measuring population ageing: an analysis of the global burden of disease study 2017. *Lancet Public Health* 4:e159–e167
14. Hou Y, et al. (2019) Ageing as a risk factor for neurodegenerative disease. *Nat Rev Neurol* 15:565–581
15. Partridge L, Fuentealba M, Kennedy BK (2020) The quest to slow ageing through drug discovery. *Nat Rev Drug Discov* 19:513–532
16. Cao Q, et al. (2020) The prevalence of dementia: a systematic review and meta-analysis. *J Alzheimers Dis* 73:1157–1166
17. Mohammed BA, et al. (2021) Multi-method analysis of medical records and MRI images for early diagnosis of dementia and Alzheimer's disease based on deep learning and hybrid methods. *Electronics* 10:2860

⁸ <https://http://www.england.nhs.uk/2021/03/nhs-celebrates-the-vital-role-hundreds-of-thousands-of-women-have-played-in-the-pandemic/>

18. Barros D, Borges-Machado F, Ribeiro Ó, Carvalho J (2020) Dementia and COVID-19: the ones not to be forgotten. *Am J Alzheimers Dis Other Demen* 35:1533317520947505
19. Sokullu R, Akkas MA, Demir E (2020) IoT supported smart home for the elderly. *Internet Things* 11:100239
20. Afanasyev I et al. Towards the internet of robotic things: analysis, architecture, components and challenges. 12th International Conference on Developments in eSystems Engineering (DeSE) 3–8 (2019).
21. Vermesan O et al. (2020) Internet of robotic things intelligent connectivity and platforms. *Front Rob AI* 7:104
22. Romeo L, Petitti A, Marani R, Milella A (2020) Internet of robotic things in smart domains: applications and challenges. *Sensors* 20:3355
23. Sun H, De Florio V, Gui N, Blondia C Promises and challenges of ambient assisted living systems. 2009 Sixth International Conference on Information Technology: New Generations 1201–1207 (2009).
24. De Carolis B, Ferilli S, Macchiarulo N Ambient assisted living and social robots: towards learning relations between user's daily routines and mood. Adjunct Proceedings of the 30th ACM Conference on User Modeling, Adaptation and Personalization 123–129 (2022).
25. Wang RH, Sudhama A, Begum M, Huq R, Mihailidis A (2017) Robots to assist daily activities: views of older adults with alzheimer's disease and their caregivers. *Int Psychogeriatr* 29:67–79
26. Bardaro G, Antonini A, Motta E (2022) Robots for elderly care in the home: a landscape analysis and co-design toolkit. *Int J Soc Robot* 14:657–681
27. McDonald A, et al. (2011) Google calendar: a new memory aid to compensate for prospective memory deficits following acquired brain injury. *Neuropsychological Rehabil* 21:784–807
28. Leng FY, Yeo D, George S, Barr C (2014) Comparison of iPad applications with traditional activities using person-centred care approach: impact on well-being for persons with dementia. *Dementia* 13:265–273
29. Jönsson K-E, Ornstein K, Christensen J, Eriksson J A reminder system for independence in dementia care: a case study in an assisted living facility. Proceedings of the 12th ACM international conference on pervasive technologies related to assistive environments 176–185 (2019).
30. McGoldrick C, Crawford S, Evans JJ (2021) MindMate: a single case experimental design study of a reminder system for people with dementia. *Neuropsychol Rehabil* 31:18–38
31. Mihailidis A, Fernie GR (2002) Context-aware assistive devices for older adults with dementia. *Gerontechnology* 2:173–188
32. Borenstein J, Arkin R (2016) Robotic nudges: the ethics of engineering a more socially just human being. *Sci Eng Ethics* 22:31–46
33. Stuck RE, Chong AW, Tracy LM, Rogers WA (2017) Medication management apps: usable by older adults? Proceedings of the Human Factors and Ergonomics Society Annual Meeting 61, 1141–1144
34. Aldeer M, Javanmard M, Ortiz J, Martin R (2022) Monitoring technologies for quantifying medication adherence. *Quantify Qual Life: Incorporat Daily Life Med* 49–78
35. Vrijens B, et al. (2012) A new taxonomy for describing and defining adherence to medications. *Br J Clin Pharmacol* 73:691–705
36. Walsh CA, et al. (2019) The association between medication non-adherence and adverse health outcomes in ageing populations: a systematic review and meta-analysis. *Br J Clin Pharmacol* 85:2464–2478
37. Salzman C (1995) Medication compliance in the elderly. *J Clin Psych*
38. Gellad WF, Grenard JL, Marcum ZA (2011) A systematic review of barriers to medication adherence in the elderly: looking beyond cost and regimen complexity. *Am J Geriatric Pharmacother* 9:11–23
39. Mason M, et al. (2022) Technologies for medication adherence monitoring and technology assessment criteria: narrative review. *JMIR mHealth and uHealth* 10:e35157
40. Turjamaa R, Vaismoradi M, Kajander-Unkuri S, Kangasniemi M (2023) Home care professionals' experiences of successful implementation, use and competence needs of robot for medication management in Finland. *Nursing Open* 10:2088–2097
41. Anderson LJ, et al. (2020) A systematic overview of systematic reviews evaluating medication adherence interventions. *Am J Health Syst Pharm* 77:138–147
42. Benjamin RM (2012) Medication adherence: helping patients take their medicines as directed. *Public Health Reports* 127:2–3
43. Ping Y, Visaria A, Suppiah SD, Tan YW, Malhotra R (2022) Prevalence and correlates of medication reminder app 'use and use intention' among older adults. *Explor Res Clin Soc Pharm* 6:100150
44. Azad N, Amos S, Milne K, Power B (2012) Telemedicine in a rural memory disorder clinic—remote management of patients with dementia. *Can Geriatr J* 15 (96)
45. McInnes DK, et al. (2017) Patient use of electronic prescription refill and secure messaging and its association with undetectable hiv viral load: a retrospective cohort study. *J Med Internet Res* 19:e34
46. Kalantarian H, Motamed B, Alshurafa N, Sarrafzadeh M (2016) A wearable sensor system for medication adherence prediction. *Artif Intell Med* 69:43–52
47. Pinto JF, Vilaça JL, Dias NS (2021) A review of current pill organizers and dispensers. *IEEE 9th International Conference on Serious Games and Applications for Health (SeGAH)* 1–8.
48. Gonzales MJ, Riek LD (2012) A sociable robotic aide for medication adherence. Proceedings of the 5th International Conference on Pervasive Technologies Related to Assistive Environments. <https://doi.org/10.1145/2413097.2413146>.
49. Prakash A, et al. Older adults' medication management in the home: how can robots help? 2013 8th ACM/IEEE International Conference on Human-Robot Interaction (HRI) 283–290.
50. Kostavelis I, et al. (2022) Robotic assistance in medication intake: a complete pipeline. *Appl Sci* 12:1379
51. Schrum M, Park CH, Howard A Humanoid therapy robot for encouraging exercise in dementia patients. 2019 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI) 564–565 (2019).
52. Góngora Alonso S, et al. (2019) Social robots for people with aging and dementia: a systematic review of literature. *Telemed E-Health* 25:533–540
53. Cruz-Sandoval D, Morales-Tellez A, Sandoval EB, Favela J A social robot as therapy facilitator in interventions to deal with dementia-related behavioral symptoms. Proceedings of the 2020 ACM/IEEE international conference on human-robot interaction 161–169 (2020).
54. Ghafurian M, Hoey J, Dautenhahn K (2021) Social robots for the care of persons with dementia: a systematic review. *ACM Transactions on Human-Robot Interaction (THRI)* 10:1–31
55. Striegl J, Gollasch D, Loitsch C, Weber G (2021) Designing vuis for social assistance robots for people with dementia. Proceedings of Mensch und Computer 2021 145–155.
56. De Carolis B, et al. (2020) Using the pepper robot in cognitive stimulation therapy for people with mild cognitive impairment and mild dementia. Proceedings of the ACHI-The Thirteenth International Conference on Advances in Computer-Human Interactions, Porto, Portugal 21–25

57. Kouroupetroglou C, et al. (2017) Interacting with dementia: the mario approach. *Harnessing Power of Technology to Improve Lives* 38–47
58. Fogelson DM, Rutledge C, Zimbro KS (2022) The impact of robotic companion pets on depression and loneliness for older adults with dementia during the covid-19 pandemic. *J Holistic Nurs* 40:397–409
59. Papadopoulos C, et al. (2022) The caresses randomised controlled trial: exploring the health-related impact of culturally competent artificial intelligence embedded into socially assistive robots and tested in older adult care homes. *Int J Soc Robot* 14:245–256
60. Dinesen B, et al. (2022) Use of a social robot (lovot) for persons with dementia: exploratory study. *JMIR Rehabil Assist Technol* 9:e36505
61. Gross HM, et al. Further progress towards a home robot companion for people with mild cognitive impairment. 2012 IEEE International Conference on Systems, Man, and Cybernetics (SMC) 637–644 (2012).
62. Tsiakas K, Abellanoza C, Makedon F (2016) Interactive learning and adaptation for robot assisted therapy for people with dementia. Proceedings of the 9th ACM International Conference on Pervasive Technologies Related to Assistive Environments 1–4.
63. Fan J, et al. (2016) A robotic coach architecture for elder care (rocare) based on multi-user engagement models. *IEEE Trans Neural Syst Rehabil Eng* 25:1153–1163
64. Yuan F, et al. (2023) Cognitive exercise for persons with alzheimer's disease and related dementia using a social robot. *IEEE Trans Rob* 39:3332–3346
65. Hebesberger D, Koertner T, Gisinger C, Pripfl J, Dondrup C (2016) Lessons learned from the deployment of a long-term autonomous robot as companion in physical therapy for older adults with dementia a mixed methods study. 2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI) 27–34.
66. Cruz-Sandoval D, Penalosa CI, Favela J, Castro-Coronel AP Towards social robots that support exercise therapies for persons with dementia. Proceedings of the 2018 ACM International Joint Conference and 2018 International Symposium on Pervasive and Ubiquitous Computing and Wearable Computers 1729–1734 (2018).
67. Cooney M, Orand A, Larsson H, Pihl J, Aksoy EE Exercising with an" iron man": design for a robot exercise coach for persons with dementia. 2020 29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)899–905 (2020).
68. Schweiger N, Wolff C Robotic support for haptic dementia exercises. 2023 IEEE 11th International Conference on Serious Games and Applications for Health (SeGAH) 1–7 (2023).
69. Valent Soler M, et al. (2015) Social robots in advanced dementia. *Frontiers in Aging Neuroscience* 7:133
70. Jøranson N, Pedersen I, Rokstad AMM, Ihlebaek C (2015) Effects on symptoms of agitation and depression in persons with dementia participating in robot-assisted activity: a cluster-randomized controlled trial. *J Am Med Directors Assoc* 16:867–873
71. Moyle W, et al. (2017) Use of a robotic seal as a therapeutic tool to improve dementia symptoms: a cluster-randomized controlled trial. *J Am Med Directors Assoc* 18:766–773
72. Chen K, Lou VW-Q, Tan KC-K, Wai M-Y, Chan L-L (2020) Effects of a humanoid companion robot on dementia symptoms and caregiver distress for residents in long-term care. *J Am Med Directors Assoc* 21:1724–1728
73. Rantanen P, Parkkari T, Leikola S, Airaksinen M, Lyles A (2017) An in-home advanced robotic system to manage elderly home-care patients' medications: a pilot safety and usability study. *Clin Ther* 39:1054–1061
74. Fattal C, et al. (2022) Perspectives on usability and accessibility of an autonomous humanoid robot living with elderly people. *Disabil Rehabil* 17:418–430
75. Rehm M, Krummheuer AL (2024) When a notification at the right time is not enough: the reminding process for socially assistive robots in institutional care. *Front Rob AI* 11:1369438
76. Khosla R, Nguyen K, Chu M-T Assistive robot enabled service architecture to support home-based dementia care. 2014 IEEE 7th International Conference on Service-Oriented Computing and Applications 73–80 (2014).
77. Wu YH, et al. (2014) Acceptance of an assistive robot in older adults: a mixed-method study of human–robot interaction over a 1-month period in the living lab setting. *Clin Interventions Aging* 801–811
78. Amabili G, et al. (2022) Social robotics and dementia: results from the aware project in supporting older people and their informal caregivers. *Int J Environ Res Public Health* 19:13334
79. Kidd CD, et al. (1999) The aware home: a living laboratory for ubiquitous computing research. *Cooperative Buildings. Integrating Information, Organizations, and Architecture: Second International Workshop, CoBuild'99, Pittsburgh, PA, USA, October 1-2, 1999. Proceedings* 2 191–198.
80. Kientz JA, et al. The georgia tech aware home. *CHI'08 Extended Abstracts on Human Factors in Computing Systems* 3675–3680 (2008).
81. Wang Q, et al. I-living: an open system architecture for assisted living. 2006 IEEE International Conference on Systems, Man and Cybernetics 5, 4268–4275 (2006).
82. Ranieri CM, MacLeod S, Dragone M, Vargas PA, Romero RAF (2021) Activity recognition for ambient assisted living with videos, inertial units and ambient sensors. *Sensors* 21:768
83. Leong TW, Johnston B Co-design and robots: a case study of a robot dog for aging people. *Social Robotics: 8th International Conference, ICSR 2016, Kansas City, MO, USA, November 1-3, 2016 Proceedings* 8 702–711 (2016).
84. Duque E, Fonseca G, Vieira H, Gontijo G, Ishitani L A systematic literature review on user centered design and participatory design with older people. Proceedings of the 18th Brazilian symposium on human factors in computing systems 1–11 (2019).
85. Tan L, Szebeko D (2009) Co-designing for dementia: the alzheimer 100 project. *Australasian Medical Journal (Online)* 185
86. Rodgers PA (2018) Co-designing with people living with dementia. *CoDesign* 14:188–202
87. Cristancho-Lacroix V, et al. (2014) A web-based program for informal caregivers of persons with alzheimer's disease: an iterative user-centered design. *JMIR Res Protoc* 3:e3607
88. Leorin C, Stella E, Nugent C, Cleland I, Paggetti C (2019) The value of including people with dementia in the co-design of personalized ehealth technologies. *Dementia and Geriatric Cognitive Disorders* 47:164–175
89. Fox S, et al. (2022) Co-design of a smartphone app for people living with dementia by applying agile, iterative co-design principles: development and usability study. *JMIR mHealth and uHealth* 10:e24483
90. Bourazeri A, Stumpf S Co-designing smart home technology with people with dementia or parkinson's disease. Proceedings of the 10th Nordic Conference on Human-Computer Interaction 609–621 (2018).
91. Tiersen F, et al. (2021) Smart home sensing and monitoring in households with dementia: user-centered design approach. *JMIR Aging* 4:e27047
92. Hwang AS, et al. (2015) Co-designing ambient assisted living (aal) environments: unravelling the situated context of informal dementia care. *Biomed Res Int* 2015
93. Antony VN, Cho SM, Huang C-M Co-designing with older adults, for older adults: robots to promote physical activity.

- Proceedings of the 2023 ACM/IEEE International Conference on Human-Robot Interaction 506–515 (2023).
94. Hsu L-J, Bays JK, Tsui KM, Sabanovic S (2023) Co-designing social robots with people living with dementia: fostering identity, connectedness, security, and autonomy. *Proceedings of the 2023 ACM Designing Interactive Systems Conference* 2672–2688.
 95. Gomes D, Mendes-Moreira J, Sousa I, Silva J (2019) Eating and drinking recognition in free-living conditions for triggering smart reminders. *Sensors* 19:2803
 96. Tamura Y, Omura T, Toyoshima K, Araki A (2020) Nutrition management in older adults with diabetes: a review on the importance of shifting prevention strategies from metabolic syndrome to frailty. *Nutrients* 12:3367
 97. Luckett T, et al. (2023) Eating and drinking-related care for persons with advanced dementia in long-term care. *Collegian* 30:548–556
 98. Richardson M, Wallace S (2014) *Getting Started with Raspberry Pi: electronic Projects with Python, Scratch, and Linux*. Inc, Maker Media
 99. Redmon J, Divvala S, Girshick R, Farhadi A (2016) You only look once: unified, real-time object detection 779–788
 100. Jocher G, et al. (2022) *ultralytics/yolov5: v7. 0-yolov5 sota real-time instance segmentation*. Zenodo
 101. Guest G, MacQueen KM, Namey EE (2012) Introduction to applied thematic analysis. *App Thematic Anal* 3:1–21
 102. Gasteiger N, et al. (2021) Robot-delivered cognitive stimulation games for older adults: usability and acceptability evaluation. *ACM Transactions on Human-Robot Interaction (THRI)* 10:1–18
 103. Aggarwal JK, Xia L (2014) Human activity recognition from 3d data: a review. *Pattern Recognit Lett* 48:70–80

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.

Emmanuel Akinrintoyo is a PhD researcher at Imperial College London. He specialises in the development of robotics and Artificial Intelligence. His research seeks to push the boundaries of human knowledge about technology development for persons with limited functional independence. Before this, he undertook his research at the Bristol Robotics Lab while completing an MRes in Robotics and Autonomous Systems at the University of Bristol and the University of the West of England. He holds an MSc in Electronic Information Engineering from Trinity College Dublin. Emmanuel's work has been funded by various scholarships.

Virginia Ruiz Garate is an Ikerbasque Research Fellow at Mondragon University within the Robotics and Automation research team. Previously, she worked as a Wallscourt Fellow researcher first, and then as an Associate Professor leading the Assistive Robotics lab, at the University of the West of England (UWE) within the Bristol Robotics Laboratory (BRL). Before, she worked as a PostDoc at the Human-Robot Interfaces and Physical Interaction laboratory of the Istituto Italiano di Tecnologia (IIT). She obtained her PhD in 2016 from the Université Catholique de Louvain (UCL) in Belgium. Virginia has developed her work under multiple international collaborative projects and she has also been serving as a reviewer for national and international projects, conferences, and journals. Her current research interests are focused on assistive robotics, human-robot interaction, and bio-inspired control.

Paul Bremner is an Associate Professor in Human-Robot Interaction at the University of the West of England (UWE) within the Bristol Robotics Laboratory (BRL). Before this he was a research fellow on a number of projects at the BRL. He obtained his PhD on conversational gestures in human-robot interaction in 2010 from UWE. His current research interests include social human-robot interaction, extended reality teleoperation interfaces and assistive robotics.