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Challenges of deploying assistive robots in real-life scenarios: an industrial perspective

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***Abstract*— With the increase in life expectancy and staff shortage, there is an urgency to understanding the needs of older adults and exploring emerging fields such as social robotics to tackle the challenges of ageing. The paper highlights the importance of providing cognitive support, physical support, reducing loneliness and increasing social engagement among older adults as well as reducing caregiver burden, and suggests that socially assistive robots (SAR) can assist older adults and their carers with such needs. However, the paper also points out that there are several challenges associated with designing and deploying SAR systems, and involving end-users in the design process is necessary to improve user acceptability and adoption. The paper describes the approaches used by PAL Robotics to facilitate real-world deployment of its ARI and TIAGo social robots, and provides examples of how these robots have been used to tackle different healthcare needs.**

I. Introduction: Aging Needs

Over the years it has been no news that life expectancy is increasing. People are living longer but that does not necessarily result in achieving quality of life in health, i.e. physical health, mental health, social health, and functional health [1]. There are several challenges that make carrying out daily activities difficult as people age, as well as challenges associated with caregivers and other stakeholders involved in health care. For this reason, it is important to understand what these needs are and what the associated challenges are in an emerging field such as social robotics.

We next present some of the main needs we believe should be prioritized:

- Cognitive support: Several studies suggest that after the age of 70 about 16% of people suffer from mild cognitive impairment worldwide [2], [3]. What is more, degenerative diseases like dementia affect over 50% of adults over 85 years old.
  Preventive treatments may slow down the rate of cortical synaptic loss produced by ageing. In response to such treatment, individuals would have a larger synaptic reserve to offset the loss that degenerative diseases cause [4]. Therefore, the use of technology to support the prevention or slowing down of the process of cognitive decline by means of cognitive training should be highly encouraged [5], [6].
- Physical support: Due to strokes or neurodegenerative diseases, falls that result in bone fractures, muscular decline or loss of mobility is not uncommon with age. Of people aged over 75 years, 30% report chronic musculoskeletal conditions; 32% report heart and circulatory conditions and 13% report endocrine or metabolic conditions[7].
  Conventional mobility equipment such as wheelchairs, crutches, or walkers, or advanced robotic equipment like exoskeletons, are all tools that may support users in their daily life such as preparing a meal, fetching objects, eating, performing house chores, or motivating users to do more physical activity [5]. Limiting such freedom of movement from one place to another has a direct negative impact on independence, self-esteem and self-reliance.
- Reduce loneliness and increase social engagement: A more hidden consequence of aging is the feeling of loneliness, due to living alone or due to lack of motivation to engage in activities. In fact, feeling lonely may result in 1.65 years' addition to one's age, accelerating the diverse aging consequences [8]. This highlights the importance of companionship and being surrounded by a healthy environment for active aging.
- Reducing caregiver burden: Due to the different consequences of ageing, older adults require even more family or care support. Caregivers and family members that can assist 24/7 are lacking, and even more so inside homes, producing a heavy burden [9]. To this end, informal caregivers should be taken into consideration when designing solutions to best reduce their caring load.

How can a technology such as a robot help tackle these needs? There has been increased research in the past few years towards the deployment of socially assistive robots (SAR) in real-world healthcare scenarios, aimed, among other applications, at assisting older adults with the different needs previously mentioned. A few examples are: providing support for cognitive training [10], [11], [12], offering companionship [13], delivering reminders or scheduling video-

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calls [14], health monitoring such as temperature control or predicting and supporting fall detection [15], [16], among others.

Such problems have been tackled in different research projects in the past by universities, institutes, and companies around the world through projects like EnrichMe [15], Hobbit [17], SPRING[1], SHAPES[2], HIRo [3], PIRC [4], VIROS [5] or MECS [6]. Besides seeking to satisfy end-users' needs, these projects have also contributed towards scientific challenges in real-world environments such as human-aware navigation [18], people detection and recognition, speech recognition, chatbots [14], [19] and advanced robot behaviors [20].

When developing assistive robotics solutions, adopting approaches involving end-users through the design and development process, such as User Centric Design (UCD), Participatory Design (PD), or Research Through Design (RtD), are considered of great importance during the different stages to favor user benefit and in turn, impact on user acceptability [21], [22].

Despite the increasing efforts put into involving end-users in the design process and selecting robot features more in sync with the needs they express, it cannot be said that at this point in time, a social robot is capable of being permanently deployed in a real-world setting while performing sufficiently well over a long period of times. Unfortunately, too many open challenges still remain to achieve such an ambitious goal [23], [24].

This paper describes some approaches that have been used by PAL Robotics to facilitate real-world deployment of its ARI [25] and TIAGo [26] social robots. Both robots are built upon ROS (Robotics Operating System) and integrate social capabilities such as social perception, speech, and dialogue management, expressive interactions, human-aware navigation, and reasoning. More specifically, we provide examples of how different healthcare needs have been tackled through different European and National healthcare projects, as well as insights and lessons learned through the process.

II. Current developments of PAL social robots that support needs of the aging population

The following sections address the challenges described in Section I throughout a few projects where PAL Robotics has contributed within the context of healthcare support for an aging population.

A. Cognitive support

SHAPES project is a European project consisting of 36 partners across Europe that aims to develop and provide a set of digital solutions to support healthy and active living of older individuals through many different pilots across Europe.

[1]https://spring-h2020.eu
[2]https://shapes2020.eu
[3]https://ife.no/en/project/human-interactive-robotics-for-healthcare-hiro/
[4]https://www.uio.no/ritmo/english/projects/pirc/
[5]https://www.jus.uio.no/ifp/english/research/projects/nrccl/
[6]https://www.mn.uio.no/ifi/english/research/projects/mecs/index.html

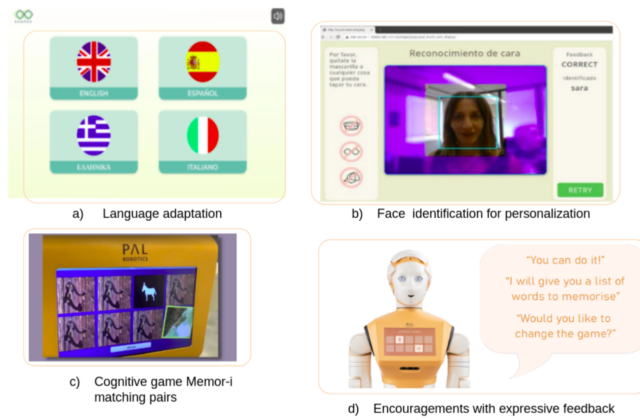

Fig. 1: SHAPES prototype for a cognitive training robot

Specifically, an ARI social robot has been adapted to be used by older adults over 65 years old who suffer from early-stage dementia, and living independently or in sheltered apartments. The goal of the different pilots has been to develop a robot that could support the elderly with cognitive games as part of physiotherapy sessions or at care-home gaming rooms for two months.

End-users in Spain, Italy, and Greece were interviewed to explore the living context of older individuals. Mock-ups and prototypes were developed through an iterative process including 7 older adults, one family member or carer for each, and 5 medical staff, with the aim of selecting the activities the robot should do and developing a user-friendly interaction. Several activities were proposed by researchers and each type of end-user would rank the activity on a 5-point Likert scale. They could also suggest new activities and prioritize them (see [12] further details). The robot would adapt its interaction language to each pilot site e.g. English, Greek, Italian or Spanish, which was included in the touch-screen, speech recognition, and a chatbot interface (Figure 1a). It would then authenticate the user through face recognition (Figure 1b) or login credentials to propose and keep track of the games played with the user. An example game is Memor-i [27], which consists of finding matching pairs, where the level of difficulty is increased depending on the user's last score (Figure 1c). Together the robot provides friendly and encouraging feedback using its voice and arm/head gestures (Figure 1d).

Lessons learned

Firstly, it is necessary to validate and re-define games that are played with a robot by involving psychologists or medical staff from early stages. Otherwise, the games may not have the required cognitive validity. For example, a game that works well on a tablet may not have the same effect on the touch-screen of a robot.

Secondly, it is very important to develop a flexible enough solution that it can adapt to different users, not only regarding the level of difficulty, but including other personalized features considered more meaningful to the user (e.g. significant themes for the user), since the cognitive decline greatly differs from one individual to another [28].

B. Physical support

To address this challenge, we will take a look at the ALMI[7] project, a collaboration with the University of York. In this application[8], a TIAGo robot provides long-term assistance to users with mild cognitive and motor impairments in the daily activity of preparing a meal. The interaction takes place via speech for voice instruction. The robot had to first understand the speech commands of the users, such as "*I want to make tea*". It would then provide step-by-step voice instructions guiding the user through meal preparation through speech. TIAGo had a knowledge base with a memory map of the objects in the kitchen, so it could use manipulation with its sensorized robotic arm to grasp and deliver each item to the user, such as food ingredients, or kitchen utensils. If it could not reach for an object it used speech to remind the user where to find it. The robot was tested in an assisted living environment lab, where it was autonomously performing the requested tasks.

The robot was tested in an assisted living environment for three weeks. In future steps, force control will be implemented in a customized version of the arm to increase safety and effectiveness in manipulation tasks.

Lessons learned

Contrary to our initial expectations, safety was prioritized over accuracy by the end users. Even if the robot did not always grasp the right object, it was more important to ensure that the robot would not harm the user. In fact, if the robot did not bring the right object, the user was actually willing to help. Thus, while we roboticists often focus their efforts on performance accuracy, we forget about the inherent and natural ability of humans to adapt and support our partners (humans or not) as needed.

C. Reduce isolation and increase social engagement

A second SHAPES pilot focuses on using the ARI robot by older people over 65 years old who live independently in rural or urban environments at Can Granada care-home (Mallorca, Spain)[9]. The robot offers[10] reminders, videocalls, the schedule for the day, entertainment games, and the option to send alerts or messages to other users with the goal of increasing social engagement [14], [29], [30]. More specifically, the robot proactively searchers for people using its autonomous navigation capabilities to deliver user-specific reminders (Figure 1). Pilots are being conducted at the time of writing this paper and are expected to be completed by July 2023.

A second project with a similar goal is the AMIBA project, which involved the AMIBA[11] day-care center, a non-profit organization in Badalona (Spain). 16 adults between 45 and

[7]https://pal-robotics.com/collaborative-projects/almi/

[8]A video of the use case can be found here: https://www.youtube.com/watch?v=VhfQmJe4IPc

[9]https://www.cangranada.com/

[10]A video of the demonstrator is available at https://www.youtube.com/watch?v=OZhJPIKn0CU

[11]http://www.amiba.22web.org/

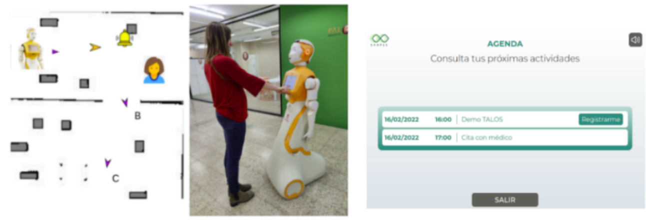

Fig. 2: ARI robot looking for a person to deliver a reminder in SHAPES.

90 years old and with a large variety of health conditions are brought in by family members to receive care during the day. Nevertheless, all individuals share the common trait of suffering from very low social engagement interest, where even caregivers struggle to involve them in conversations. A short process of observation of daily routines at the day-care center, as well as interviews with staff members, took place to gather initial insights on how to provide support in the activities carried out. The robot stayed at the center for only one week, welcoming users, providing announcements about meal times or specific therapy sessions, and as a companion during physical therapy group sessions. Details on the prototype and pilot testing are described in [28].

Lastly, in the NHoA[12] project (Never Home Alone) a co-design process has been started with the aim of identifying needs, desires, and barriers towards achieving a better quality of life by mitigating situations of loneliness. Similar to other projects, we have started by exploring such requirements by running individual interviews. It was paramount not to only include potential end-users (10 older adults over 61 years old), but also their ecosystem when it comes to providing care to the elderly. Thus, we also interviewed their informal caregivers (5) and healthcare professionals, including geriatricians, nurses, general practitioners, a psychiatrist, a psychologist, and occupational therapists (10 in total). We are also interested in hearing their voices through the initial design process. Thus, we ran a first workshop where we invited participants to take part in a brainstorming session, i.e. the starting phase of the innovation process, aiming at actively involving them in the conceptualization process of a future prototype. The next steps are to further evolve the initial ideas into concepts and create quick prototypes (wireframe prototypes) to undergo validation iterations with the end-users before completing the first working prototype.

Lessons learned Throughout the iterative development end-users highlighted placing importance on non-medical reminders/suggestions such as birthdays or movie reminders, as well as activities like bingo or videocalls [31] that promoted interaction with friends. In other words, they were expecting the robot to play a facilitator role in social interactions, which could be potentially used as a mediator in group settings to positively influence conversational dynamics in human-human interactions.

Another role that older adults instinctively attributed to

[12]https://nhoa-project.eu/

the robot was that of a partner in group-based gross motor activity training. The intended original robot's role was to lead the session along with the therapist. However, since the robot was not able to perform all the required motions, and in fact was a little clumsy, they somehow empathized with it, commenting on how badly or nicely it was performing in different cases. We believe that by observing the robot, they felt empowered and actually motivated to show the robot how the exercises should be done. Moreover, while playing the role of a partner, the therapist's leading role is reinforced, while the whole group, the robot included, follows him/her motivated by each other [31].

A future key feature that calls for improvement from the caregiver's perspective is to facilitate tools to easily command the robot, preferably by voice, for them to decide when to start/end an activity/action, rather than having it working autonomously. Thus, a sense of control, to a greater or lesser degree depending on the context of use, is essential for users to impact the adoption of new technologies in their daily activities.

D. Reduce caregiver burden

This challenge is being addressed in the SPRING project[13] [19]. In this context, the robot is used as a receptionist robot at a hospital in Paris (Broca living lab), to welcome users, help with administrative forms, announce appointments, and guide users or entertain them. These tasks were identified by the stakeholders as highly time-consuming tasks, especially during peak hours. Of those tasks, the most highly appreciated were the welcoming and patient guidance activities, where healthcare staff felt their burden was significantly reduced.

In DIH HERO SANDRO project[14], a TIAGo robot is used to provide assistive services to staff members at the Socioasanitari El Carme in Badalona (Spain). Three main activities were developed[15]: security patrol, where TIAGo is sent to check potential emergency calls from patients; patient monitoring checks, where the robot checks room by room the patients' safety status, i.e. whether any fall has occurred; and promoting physical exercises, where TIAGo is sent to visit designated patients to perform gross motor exercises. Staff members can instruct the robot to perform different activities by using a tablet. At the same time, any notification from the robot is sent to the tablet, so the staff can immediately take action when needed. Through this process, staff members have reduced unnecessary time devoted to only transit from the reception area to the room.

Lessons learned Similar to the AMIBA project, an easier interface to command the robot was considered essential and should be tackled in the near future to effectively support the hospital staff.

Table I summarizes needs already addressed through different approaches and those that are yet to be taken into consideration.

III. Challenges for the real-life deployment of social robots

We have talked about needs and how we develop prototypes to help with those needs. However, we have not yet addressed the many technical challenges that we must face when actually deploying robots in the field [32]. This section highlights some of the challenges encountered during this process, and how we addressed some of these.

A. Technical challenges of real-world deployment

Real-world deployment brings technical challenges that are not seen in lab settings [23]. In the SHAPES project, the robot navigated inside homes, looking for the user in order to deliver reminders. Many areas had to be put off limits because they were too narrow, or the robot would have had to go over thick carpets or steps to reach them. Older adults spent a considerable amount of time around these areas, and thus the robot often failed to find them.

In SPRING, the robot acted as a receptionist. It had to feature situated multi-party interaction capabilities requiring complex integration of different cognitive modules. With interactions mostly based on verbal communication, the current limitations in the robustness of speech recognition and dialog systems were significant obstacles.

We developed several tools and techniques to mitigate some of these challenges.

Tools for safer navigation

Navigation in home settings has been a big challenge for a robot like ARI, due to the dynamic nature of homes, the reluctance of older individuals to relocate objects, presence of narrow areas (Figure 3a), carpets (Figure 3b) or steps, and size of the robot (Figure 3c).

To overcome this challenge to an extent, maps have to be enriched with additional restricted areas. To this end, PAL Robotics robots include a Web-based GUI interface (called *WebGUI*) to facilitate map manipulation. Figure 4 shows an example of the map editing process with WebGUI.

The following steps are carried out to build a map of the environment whenever a new setup is required at an end-user:

- While the robot is tele-operated by an engineer using the WebGUI, through slow and rotational movements around the environment, ROS rosbags – file format in ROS for storing ROS message data[16] – are recorded and saved in an external hard-drive. Data consists of camera data (RGB or RGB-D) and odometry data;
- The occupancy grid map is saved and displayed on the WebGUI. Points of Interests (POIs) are added to mark safe locations where the robot could go to. For example, the center of the living room or the side of a door (see Figure 4);
- Dangerous areas, such as steps, or places where the robot should not go, such as toilets or private rooms, are

[13]https://cordis.europa.eu/project/id/871245

[14]https://dih-hero.eu/sandro

[15]A video of a pilot can be seen at https://www.youtube.com/watch?v=qSM9h7JRdBM

[16]http://wiki.ros.org/Bags

TABLE I: Needs and challenges encountered in healthcare robotics sector

What works	What we need to work on
• Navigation at home-settings • Basic speech interaction in multiple languages • Cognitive games with a robot that provides encouragement • Robot that delivers reminders, videocalls, welcomes users • Robot as a tool for promoting group activities • Support in preparing meals in the kitchen in a safe way	• Provide easier ways to control the robot for non-tech users and teach robots new things (games, activities) • Focus on non-medical activities and those that promote interaction with other people • Prioritize safety and robustness over accuracy • Tighter collaboration with health personnel for robot design • Better metrics to evaluate deployment progress

(a) (b) (c)

Fig. 3: (a) ARI entering the kitchen. (b) ARI walking on a carpet. (c) ARI navigating on the terrace

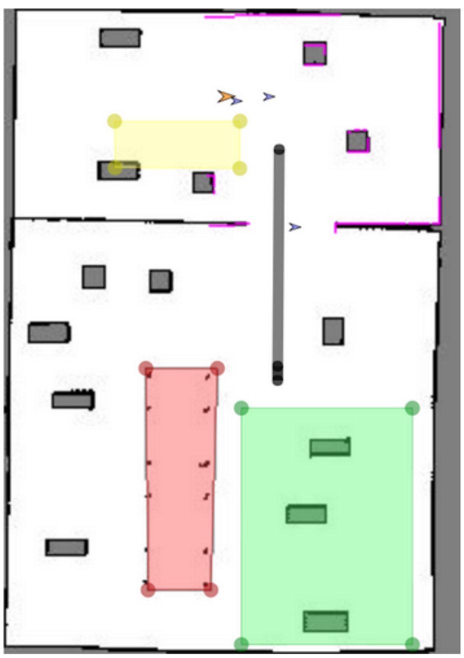

Fig. 4: Virtual obstacles (red), Zones of Interest (green) and Points of Interest are used to restrict map areas and points where the robot can navigate to

marked as Virtual Obstacles (VO). Thus, as the robot navigates around, it will plan a path to avoid such areas;

- In contrast to POIs, larger areas, such as the kitchen, and living room, can be also identified as Zones of Interest. When the robot is told to go to a given ZOI, it will consider the navigation task successful as long as it ends within that area;
- For the robot to charge itself automatically, a docking station is placed on a flat wall, and the robot is instructed to "Learn Dock" in order to detect the ARUco marker attached to the docking station and add its location on the map. Thus, whenever the robot detects its battery is low, it will automatically go back to charge;
- On-site testing: with the annotated map, navigation tests take place in the real environment to fine-tune it accordingly, both at different times of the day and over several days. This way we ensure that the robot has built a robust enough map.

It should be noted that all PAL robots use ROS for autonomous navigation, specifically the `move_base` stack[17]. As such, they are capable of performing both obstacle avoidance and path planning. In some situations, low-level parameters of the robot are modified, such as maximum speed and acceleration or inflation radius of the cost map to ensure the robot can go through narrower areas.

ROS4HRI compliance

In order to model complex autonomous systems for multi-user interaction, as is the case with a receptionist robot, the focus is on the software integration of human perception, speech interaction, navigation, and low-level and high-level decision-making systems, together with universities involved in the EU projects. Specifically, we developed and implemented on all our robots the ROS4HRI [33] standard (*ROS for Human-Robot Interaction*), an umbrella project for all the ROS packages, conventions, and tools that help to develop interactive robots with ROS[18]. Among other features, ROS4HRI allows the robot to uniquely identify each user by

[17]http:wiki.ros.org/move_base
[18]http://wiki.ros.org/hri

a given ID, either by face, body or voice, enabling multi-user interaction and easier integration of components through ROS.

We use the ROS4HRI standard as a backbone for our cognitive software architectures, like the one created in the SPRING project. Figure 5 provides a complete picture of the architecture, with more than 40 ROS nodes combined together to manage multi-party interactions. In the picture, each color represents a cognitive function, such as perception, speech interaction, decision-making, and navigation.

Speech interaction improvements

Speech interaction remains one of the big challenges in achieving a fluent and engaging human-robot interaction, but also one of the most important to overcome. In most pilots conducted so far, what people especially have wanted to do is to chat with the robot [34], [35]. The type of microphone, ambient noise, different dialects and languages, lack of WiFi or problems in achieving ethical approvals for cloud-based solutions, all affect the performance of speech recognition, degrading it even more when it comes to multi-user interaction since many studies so far have focused on single interactions. We have to address questions such as: When should the robot start listening? Who should it listen to? Who is saying what?

While in practice many of the speech-related capabilities remain open challenges, the ARI robot has been progressively improved and tested in hospital settings, addressing some of these problems as follows:

- Integration of a 4-mic Microphone Array, the ReSpeaker Mic Array v2.0[19], with capabilities for Voice Activity Detection, de-reverberation, and echo cancellation [25];
- Easy integration of multiple speech recognition (ASR) systems, both online (Google and ALANA in SPRING [19], Adilib recognizer from VICOM on SHAPES [14]), and offline (Vosk[20]);
- Acapela text-to-speech in different languages[21];
- Integration of multiple NLP (Natural Language Processing) and chatbots, both online (ALANA in SPRING, Adilib for SHAPES, Dialogflow[22]), and offline (RASA[23].
- Following recent trends, we are also currently experimenting with the integration of LLMs (eg ChatGPT), albeit with many open questions remaining regarding how such systems can be properly constrained to specific domains.

In projects like AMIBA or in-home settings, it is often difficult to rely on Internet connectivity, which is why the default speech tools for the robot are the combination of offline tools Vosk, Acapela and RASA, also enabling low-latency speech interaction.

All these components are integrated through the ROS4HRI standard [36]. Thanks to this, each voice and speech detected is uniquely linked to a person, which can be used for multi-user interaction, and for more advanced development of robot behaviors, e.g. turn-taking, small talk, or interruptions. These last-mentioned features are still being researched in projects like SPRING.

We have made an additional effort to improve the accessibility of verbal interactions by introducing bidirectional subtitles on the touch-screen of the robot for both what the robot understands and says. This reduces user frustration, as they can see if the robot has understood or not, and what was spoken out. It is particularly beneficial in noisy environments such as public spaces.

Safer manipulation control technique

The TIAGo robot's arm was re-designed to include force control (thus enabling active compliance) and wider workspace access to manipulate objects more safely and avoid risks to humans in case of collision. A new controller for self-collision has also been developed through Whole Body Control[24], which allows the robot to be endowed with safer control techniques to assist in the manipulation activities in unstructured home environments.

B. Increase robot acceptability

Increasing robot acceptability [37] is a critical challenge that must be addressed if we really want robots to be adopted by society. In projects like AMIBA or SHAPES, users did not feel confident enough to use the robot on their own, and in practice required a technical person to be present.

The most prominent difficulty, though, is the high level of expectations that users form about the capabilities of the robot, assuming it would work out-of-the-box. This is compounded by the difficulty of engaging with future end-users (often already overloaded with their own professional duties) into the detailed co-design process with the engineers, This happened clearly in the AMIBA project, where adoption of the robot proved to be an extra workload for their already-packed schedules, negatively impacting their willingness to use the robot.

In addition, interestingly, many older adults simply had no interest in a robot and mistrusted it and fearing that it would only increase their loneliness [13].

Adopting participatory design approaches to explore users' daily routines on the one hand, and discussing with experts about the domain's potential applications and their implications on the other, is essential to maximize acceptance while tackling the problem from a holistic approach. In the AMIBA project for instance, due to the short period of time that the project was active, we only had the chance to iterate through the design process twice and had several limitations: lack of time when fixing issues encountered during on-site testing (e.g. integration of the offline voice interaction pipeline; improved interface or robot autonomy for activity selection). However, during this time frame, it was possible to at least understand what end-users valued more and expose older adults to interaction with a robot.

[19]https://respeaker.io
[20]https://alphacephei.com/vosk/
[21]https://www.acapela-group.com/
[22]https://cloud.google.com/dialogflow
[23]https://rasa.com/
[24]https://pal-robotics.com/whole-body-control/

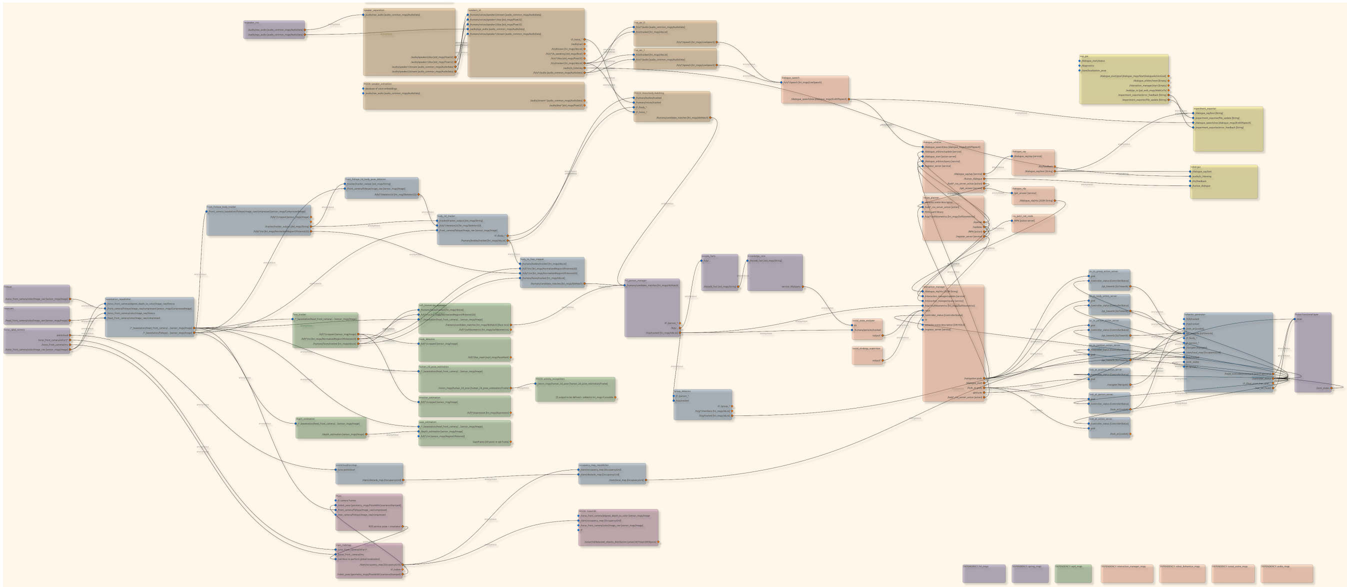

Fig. 5: Software architecture of the SPRING project. Colours roughly correspond to cognitive functions: perception (blue, left), speech processing (beige), social perception (green), mapping and navigation (pink, bottom), decision-making (salmon), and executive layer (blue, right).

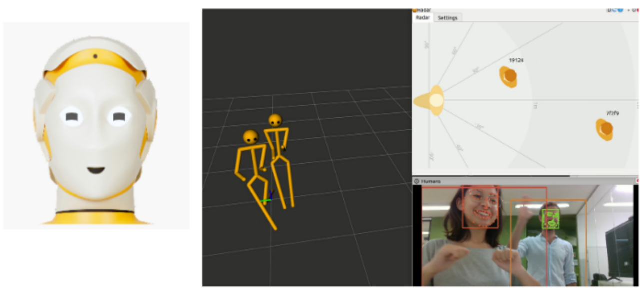

Fig. 6: Expressive eyes (left) and unique identification with an ID for each user using ROS4HRI (right)

Another important feature to increase the engagement of users and motivate people to interact with the robot is by exploiting the robot's expressiveness [32], as expressive behaviors motivate self-disclosure i.e. boosting empathy, building trust [38] and making people feel closer. The ARI robot has two animated eyes on each of its LCD screens. Different expressions for eyes have been designed (Figure 6), that can be linked to speech text phrases with the use of tags, e.g. `"I am happy to see you 'eyes=happy'"`. Similarly, expressive body gestures can be designed using the robot's WebGUI interface, and combined with its speech. For example, `"'doTrick=wave' I am happy to see you"`. The robot has modules such as engagement detection, attention manager, and face tracking (Figure 6) as part of the ROS4HRI framework to provide a layer of human awareness in the architecture, which in turn, increases its liveliness by responding to the users' states.

IV. Conclusions

In conclusion, the implementation of robots in the healthcare sector has opened up new avenues for improving the quality of life for older adults by addressing different needs. However, pilot studies in real-life scenarios still face many challenges such as speech interaction, indoor navigation and, more than anything, meeting end-users' expectations, but the paper indicates some efforts that have been made toward countering such challenges. Robots are a disruptive technology, as such, setting correct initial expectations, and carrying out heavy testing with real situations and end-users, is key to gradual adoption.

For proper evaluation of the success of robot adoption, a proper benchmarking tool and KPIs are needed that evaluate, for instance, robustness, adaptability, acceptance, and engagement levels. Robotics in healthcare is a promising area that can revolutionize the way we care for older adults, and with further research and development, we can expect to see more advanced robots in this field in the future.

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REFERENCES

[1] G. C. Brown, "Living too long: the current focus of medical research on increasing the quantity, rather than the quality, of life is damaging our health and harming the economy," *EMBO reports*, vol. 16, no. 2, pp. 137–141, 2015.

[2] N. A. Bishop, T. Lu, and B. A. Yankner, "Neural mechanisms of ageing and cognitive decline," *Nature*, vol. 464, no. 7288, pp. 529–35, 2010.

[3] J. E. Morley, J. C. Morris, M. Berg-Weger, S. Borson, B. D. Carpenter, N. del Campo, B. Dubois, K. Fargo, L. J. Fitten, J. H. Flaherty, M. Ganguli, G. T. Grossberg, T. K. Malmstrom, R. D. Petersen, C. Rodriguez, A. J. Saykin, P. Scheltens, E. G. Tangalos, J. Verghese, G. Wilcock, B. Winblad, J. Woo, and B. Vellas, "Brain health: The importance of recognizing cognitive impairment: An iagg consensus conference," *Journal of the American Medical Directors Association*, vol. 16, no. 9, pp. 731–739, 2015.

[4] D. L. Murman, "The impact of age on cognition," *Seminars in Hearing*, vol. 36, pp. 111–121, 2015.

[5] J. S. McPhee, D. P. French, D. Jackson, J. Y. Nazroo, N. Pendleton, and H. Degens, "Physical activity in older age: perspectives for healthy ageing and frailty," *Biogerontology*, vol. 17, pp. 567–580, 2016.

[6] M. E. Butler, E. M. McCreedy, V. A. Nelson, P. Desai, E. R. Ratner, H. A. Fink, L. S. Hemmy, J. R. McCarten, T. R. Barclay, M. Brasure, H. Davila, and R. Kane, "Does cognitive training prevent cognitive decline?" *Annals of Internal Medicine*, vol. 168, pp. 63–68, 2018.

[7] E. G. Christoforou, S. Avgousti, N. Ramdani, C. Novales, and A. S. Panayides, "The upcoming role for nursing and assistive robotics: Opportunities and challenges ahead," *Frontiers in Digital Health*, vol. 2, 2020.

[8] F. Galkin, K. Kochetov, D. Koldasbayeva, M. Faria, H. H. Fung, A. X. Chen, and A. Zhavoronkov, "Psychological factors substantially contribute to biological aging: evidence from the aging rate in chinese older adults," *Aging*, vol. 14, no. 18, pp. 7206–7222, 2022.

[9] M. Bastawrous, "Caregiver burden—a critical discussion," *International Journal of Nursing Studies*, vol. 50, no. 3, pp. 431–441, 2013.

[10] F. S. Alnajjar, S. Khalid, A. A. Vogan, S. Shimoda, R. Nouchi, and R. Kawashima, "Emerging cognitive intervention technologies to meet the needs of an aging population: A systematic review," *Frontiers in Aging Neuroscience*, vol. 11, 2019.

[11] E. Nault, L. Baillie, and F. Broz, "Investigating the usability of a socially assistive robotic cognitive training task with augmented sensory feedback modalities for older adults*," *2022 31st IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*, pp. 735–742, 2022.

[12] I. Dratsiou, A. Varella, E. Romanopoulou, O. Villacañas, S. Cooper, P. Isaris, M. Serras, L. Unzueta, T. Silva, A. Zurkuhlen, M. MacLachlan, and P. D. Bamidis, "Assistive technologies for supporting the wellbeing of older adults," *Technologies*, vol. 10, no. 8, 2022.

[13] S. Coghlan, J. Waycott, A. Lazar, and B. Barbosa Neves, "Dignity, autonomy, and style of company: Dimensions older adults consider for robot companions," *Proc. ACM Hum.-Comput. Interact.*, vol. 5, no. CSCW1, 2021.

[14] S. Cooper, A. Di Fava, Villacañas, T. Silva, V. Fernandez-Carbajales, L. Unzueta, M. Serras, L. Marchionni, and F. Ferro, "Social robotic application to support active and healthy ageing," in *2021 30th IEEE International Conference on Robot Human Interactive Communication (RO-MAN)*, 2021, pp. 1074–1080.

[15] S. Coşar, M. Fernandez-Carmona, R. Agrigoroaie, J. Pages, F. Ferland, F. Zhao, S. Yue, N. Bellotto, and Tapus.

[16] D. Saplacan and J. Tørresen, "Robots as welfare technologies to reduce falls amongst older adults: An explorative study from norway," in *Human Aspects of IT for the Aged Population. Technology in Everyday Living: 8th International Conference, ITAP 2022, Held as Part of the 24th HCI International Conference, HCII 2022, Virtual Event, June 26–July 1, 2022, Proceedings, Part II*. Springer, 2022, pp. 88–106.

[17] D. Fischinger, P. Einramhof, K. E. Papoutsakis, W. Wohlkinger, P. Mayer, P. Panek, S. Hofmann, T. Körtner, A. Weiss, A. A. Argyros, and M. Vincze, "Hobbit, a care robot supporting independent living at home: First prototype and lessons learned," *Robotics Auton. Syst.*, vol. 75, pp. 60–78, 2016.

[18] R. Möller, A. Furnari, S. Battiato, A. Härmä, and G. M. Farinella, "A survey on human-aware robot navigation," *Robot. Auton. Syst.*, vol. 145, no. C, nov 2021. [Online]. Available: https://doi.org/10.1016/j.robot.2021.103837

[19] N. Gunson, D. Hernandez Garcia, W. Sieińska, A. Addlesee, C. Dondrup, O. Lemon, J. L. Part, and Y. Yu, "A visually-aware conversational robot receptionist," in *Proceedings of the 23rd Annual Meeting of the Special Interest Group on Discourse and Dialogue*. Edinburgh, UK: Association for Computational Linguistics, Sept. 2022, pp. 645–648. [Online]. Available: https://aclanthology.org/2022.sigdial-1.61

[20] S. Cooper and S. Lemaignan, "Towards using behaviour trees for long-term social robot behaviour," in *2022 17th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, 2022, pp. 737–741.

[21] M. Spargo, N. Goodfellow, C. Scullin, S. Grigoleit, A. Andreou, C. X. Mavromoustakis, B. Guerra, M. Manso, N. Larburu, Villacañas, G. Fleming, and M. Scott, "Shaping the future of digitally enabled health and care," *Pharmacy*, vol. 9, no. 17, 2021.

[22] J. Trischler, S. J. Pervan, S. J. Kelly, and D. R. Scott, "The value of codesign: The effect of customer involvement in service design teams," *Journal of Service Research*, vol. 21, no. 1, pp. 75–100, 2018.

[23] K. M. Gerling, D. Hebesberger, C. Dondrup, T. Körtner, and M. Hanheide, "Robot deployment in long-term care," *Zeitschrift Fur Gerontologie Und Geriatrie*, vol. 49, pp. 288 – 297, 2016.

[24] P. Share and J. Pender, "Preparing for a robot future? social professions, social robotics and the challenges ahead," *Irish Journal of Applied Social Studies*, vol. 18, p. 4, 2018.

[25] S. Cooper, A. D. Fava, C. Vivas, L. Marchionni, and F. Ferro, "Ari: the social assistive robot and companion," *2020 29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*, pp. 745–751, 2020.

[26] J. Pagès, L. Marchionni, and F. Ferro, "Tiago: the modular robot that adapts to different research needs," 2016.

[27] U. Zwick and M. S. Paterson, "The memory game," *Theor. Comput. Sci.*, vol. 110, no. 1, p. 169–196, mar 1993. [Online]. Available: https://doi.org/10.1016/0304-3975(93)90355-W

[28] K. Tsiakas, M. Abujelala, and F. Makedon, "Task engagement as personalization feedback for socially-assistive robots and cognitive training," *Technologies*, vol. 6, no. 2, 2018. [Online]. Available: https://www.mdpi.com/2227-7080/6/2/49

[29] S. Cooper and F. Ferro, "Lessons learnt from deploying ari in residential care," 2022.

[30] S. Cooper, Óscar Villacañas, L. Marchionni, and F. Ferro, "Robot to support older people to live independently," 2021.

[31] M. Traeger, S. S. Sebo, M. F. Jung, B. Scassellati, and N. A. Christakis, "Vulnerable robots positively shape human conversational dynamics in a human–robot team," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 117, pp. 6370 – 6375, 2020.

[32] G. Cortellessa, R. D. Benedictis, F. Fracasso, A. Orlandini, A. Umbrico, and A. Cesta, "AI and robotics to help older adults: Revisiting projects in search of lessons learned," *Paladyn, Journal of Behavioral Robotics*, vol. 12, no. 1, pp. 356–378, 2021. [Online]. Available: https://doi.org/10.1515/pjbr-2021-0025

[33] Y. Mohamed and S. Lemaignan, "Ros for human-robot interaction," in *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2021, pp. 3020–3027.

[34] M. Marge, C. Espy-Wilson, N. G. Ward, A. Alwan, Y. Artzi, M. Bansal, G. Blankenship, J. Chai, H. Daumé, D. Dey, M. Harper, T. Howard, C. Kennington, I. Kruijff-Korbayová, D. Manocha, C. Matuszek, R. Mead, R. Mooney, R. K. Moore, M. Ostendorf, H. Pon-Barry, A. I. Rudnicky, M. Scheutz, R. S. Amant, T. Sun, S. Tellex, D. Traum, and Z. Yu, "Spoken language interaction with robots: Recommendations for future research," *Computer Speech &amp Language*, vol. 71, p. 101255, jan 2022. [Online]. Available: https://doi.org/10.1016%2Fj.csl.2021.101255

[35] M. Forsberg, "Why is speech recognition difficult?" 2003.

[36] S. Lemaignan, S. Cooper, R. Ros, L. Ferrini, A. Andriella, and A. Irisarri, "towards-source natural language processing on the pal robotics ari social robot," in *Companion of the 2023 ACM/IEEE International Conference on Human-Robot Interaction*, ser. HRI '23. New York, NY, USA: Association for Computing Machinery, 2023, p. 907–908. [Online]. Available: https://doi.org/10.1145/3568294.3580041

[37] S. Whelan, K. Murphy, E. Barrett, C. Krusche, A. Santorelli, and D. Casey, "Factors affecting the acceptability of social robots by older adults including people with dementia or cognitive impairment: A literature review," *International Journal of Social Robotics*, vol. 10, pp. 643–668, 2018.

[38] Y. Noguchi, H. Kamide, and F. Tanaka, “Personality traits for a social mediator robot encouraging elderly self-disclosure on loss experiences,” *ACM Transactions on Human-Robot Interaction (THRI)*, vol. 9, no. 3, pp. 1–24, 2020.