ARI: the Social Assistive Robot and Companion

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Abstract— **With the world population aging and the number of healthcare users with multiple chronic diseases increasing, healthcare is becoming more costly, and as such, the need to optimise both hospital and in-home care is of paramount importance. This paper reviews the challenges that the older people, people with mobility constraints, hospital patients and isolated healthcare users face, and how socially assistive robots can be used to help them. Related promising areas and limitations are highlighted. The main focus is placed on the newest PAL Robotics' robot: ARI, a high-performance social robot and companion designed for a wide range of multi-modal expressive gestures, gaze and personalised behaviour, with great potential to become part of the healthcare community by applying powerful AI algorithms. ARI can be used to help administer first-care attention, providing emotional support to people who live in isolation, including the elderly population or healthcare users who are confined because of infectious diseases such as Covid-19. The ARI robot technical features and potential applications are introduced in this paper.**

I. INTRODUCTION

World population is aging, and projections from Europe, USA, and Asia foresee that the number of people older than 64 will increase by more than 70% because of an increase in average lifespan. The World Health Organization (WHO[6]) estimates that by 2050 the number will increase to 2 billion from the 900 million in 2015.

Healthcare spending has in the last few decades grown steadily, from 4-6% of Gross Domestic Product (GDP) in 1970 to an average 8.8% in 2019 (statistics from OECD-countries[7]). In the coming years, this spending is expected to keep increasing, due to a number of factors, including the fact that the proportion of older people among the population will be increasing, escalating costs per work hour in the health-care sector[1] and investment in healthcare technology[2], affecting even more those with lower socioeconomic status and with multiple chronic conditions.

This also means that there will be fewer hands to take care of those requiring healthcare [3], [4], increasing the healthcare burden. Efficient technological solutions have the potential to improve the quality of healthcare services at the same time as keeping costs and staff requirements manageable.

In the last few years the healthcare sector has been attempting to shift hospital care to homes in order to reduce hospital stays and their cost [3]. For patients it is more familiar, convenient and cost-effective to stay at their homes while they can receive regular care, remote monitoring and support, delivered by community nurses or caregivers. Caregivers can coordinate with patients' clinicians and exchange data through *eHealth*, becoming part of an integrated care system. By shifting care to the home, re-admission to nursing homes or hospitals may be prevented, with consequent cost-saving, in particular for rural areas where healthcare centres may be too far away.

Loneliness and lack of engagement with the community can be experienced by older people that are living alone, but that still want to live as independently as possible in their homes [5], even among older patients with good overall health. Furthermore, there is a high incidence of strokes among the older population [6] and it is important that they receive intensive and frequent rehabilitation therapy, help in other physical activities at home and general entertainment to improve their mood, which can be difficult due to lack of human resources.

Robots have significantly impacted on the healthcare sector by means of surgical, rehabilitation or assistance robots [7]. Healthcare robots, in particular *Socially Assistive Robots* (SAR) can help in reducing emergency visits and healthcare costs, and encourage independent living, while also reducing caregiver burden [3]. In a hospital context, healthcare robots can become a part of the "Smart hospital of the future", consisting of an environment integrated with diverse technologies and functions with the goal of empowering patients, optimizing patient cases, and processing automation and alerts [8].

The rest of the paper is organized as follows. Section II provides an overview of healthcare robots focusing on SAR, their features and possible uses, and highlighting the needs during contagious diseases such as *Covid-19*. Then possible limitations and challenges of SAR are examined in Section III. Section IV presents the ARI robot, the new robot companion and social assistive robot, focusing on its features and applications. Finally, a brief conclusion is presented in Section V.

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[6]https://www.who.int/news-room/fact-sheets/detail/ageing-and-health

[7]http://www.oecd.org/health/health-data.htm

[8]https://www.sdglobaltech.com/blog/the-many-benefits-of-integrated-patient-rooms-in-smart-hospitals

II. Healthcare robots overview

As healthcare robotics has only started growing significantly in the past few years, there is no standardised method for classifying them as yet. Considering the classification of several related works [8], [3], [9] a possible general classification might consist of the following categories:

- Surgical robots
- Mobile logistics robots
- Robots for mobility and rehabilitation
- Personal assistant robots

Aside from robotic surgery, which is the main area in healthcare where robots have been used, some of the opportunities arising now include administering of hospital logistics: smart inventory management systems, efficient transport of hospital materials such as blood samples, diagnostic tests and food delivery, and medicine delivery at the request of a medical professional to the patient's rooms by autonomous robot, to name some examples. Right now the main challenges in this field are ensuring safety in crowded areas by suitable sensing abilities as well navigation from floor to floor and through narrow areas [9].

Rehabilitation robots adapt and interact with patients physically with the aim of restoring functionality, especially for those that have suffered strokes or spinal cord injuries and need post-stroke therapy. They may provide support to a patient's weight as they walk (SoloWalk, by McCormick et al. [10]). Related robots are exoskeletons such as ReWalk [11], used among people with paralysis, which help users walk and climb stairs to compensate for their lack of regular physical abilities with positive outcomes. Brain-computer interface controlled robots such as wheelchair-mounted robotic arms [12] or robot prosthetics can help such users or those with limb loss carry out manipulation tasks.

However, recently there has been a focus in robotics research on the use of personal assistant robots, "robots designed for living together with and assisting human beings", by using robots that can collaborate and communicate with people. Personal assistant robots are still not used much in real applications, but are expected to grow in demand. These can be of classified into two types:

- Physically assistive robots
- Socially assistive robots: therapy, companion, entertainment and telepresence robots

Such assistive robots could be used at homes to assist in daily activities like cooking, cleaning, eating, and especially handovers, where the robot brings an object requested by the end-user. Two examples of such robots are shown in Figure 1. Personalised dressing assistance is another interesting area of research, as it involves daily living activity that entails the greatest burden on caregivers, with some work carried out by Zhang et al. [13], using a dual-armed Baxter robot. However, this is complex due to many older people having limited upper-body movements and the need for a real-time system that adapts to quick unexpected behaviour.

There are also many novel robots that are being designed and tested to target specific tasks, robots like Robear can aid in lifting and transferring older people and those with paralysis from bed to wheelchair [14], which is especially physically demanding and risky for nurses.

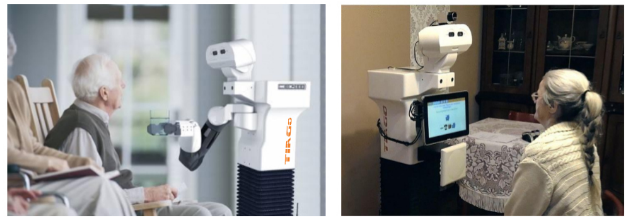

Fig. 1: Two versions of older Robotics' TIAGo for object fetching (left) and interacting with older adults for enRichMe project (right)

A. Socially Assistive Robots (SAR)

A special group of Healthcare robots is the Socially Assistive Robots [15], [6], [16]. SAR focus on communication with the aim of enhancing users' health and psychological well-being through diagnosis, therapy, or offering companionship [17] to those who feel lonely. One of the major advantages of therapy robots is that users can have access to them whenever they need them, rather than depending on therapist availability.

Table I summarises how SARs can be of help for different types of users. The table has been developed based on PAL Robotics' experience in healthcare related works such as EnrichMe[9], SOCRATES[10], SPRING[11] and SHAPES[12] H2020 projects, not to mention the user-centered design and market analysis carried out for all PAL Robotics' robots.

SAR are "robots that assist users by providing social interactions such as appropriate emotional or social cues" [9]. Positive outcomes have been obtained in the health sector as they increase motivation and quality of life [15], [6], [16]. In the context of health, they can offer personalised care and encouragements, interact in many languages, call users attention, make appointments through speech or reminding users to take their medicine, as well as early diagnosis and continuous health assessment and monitoring.

SAR can be pet-like, such as Paro, Aibo or iCat, who can serve as stress relief [19] and encourage interaction between older people. Research has demonstrated that robots like Paro can reduce stress and anxiety among older people with dementia [20] and may also serve as user-adapted telepresence robots. Telepresence robots "enable an operator to be virtually present at a remote location and to provide actuators that enable the operator to interact with the remote environment" [9]. Some commercial humanoid robots like

[9] http://pal-robotics.com/collaborative-projects/enrichme/
[10] http://www.socrates-project.eu/
[11] https://spring-h2020.eu/
[12] https://shapes2020.eu/

TABLE I: Potential use of SAR robots for different types of users

Potential user	Needs	SAR benefits
Older people: frail, those with severe chronic conditions, with neurodegenerative diseases.	• Isolation and boredom • Cognitive and physical decline • Forgets to do tasks, does not know where some things are • Monitoring the progression of illness	• Engage users with community (telepresence), share news, social events • Play cognitive games, physical exercises and other in-home activities customised to their interests and capabilities • Remind users to take medications, how to do tasks • Monitoring of vital functions, risks (gas, fire hazards, users falling), cognitive functions
Users with mobility or physical difficulties (adults / older adults) due to paralysis, loss of limb, general physical weakness.	• Cannot walk independently • Need help in physical manipulation tasks • Need of carrying out rehabilitation exercises regularly and frequent monitoring • Want to be up to date with their illness	• Guide and support in navigation • Fetch objects, including teleoperation ability • Offer physical rehabilitation games • Remote monitoring • Emergency support, fall detection and alerts
Isolated patients or users with special needs that require remote monitoring.	• Isolation and boredom • Communication with professionals • Monitoring the progression of illness	• Engage users with community and professionals (telepresence), share news, social events • For people isolated due to an infection, it also reduce risk of spreading the disease • Hospital staff can monitor and make requests of robot actions through internet • Encourage children with autism to develop and use social skills and engage them in conversation [18]
Patients in waiting rooms or entrance of hospitals and care centers [5].	• Boredom while waiting • Patient logistics • Monitoring the progression of illness	• Can serve as companions and provide entertainment, including cognitive games • Access to users personal health records in order to provide assessment, enable smart appointments scheduling • Give information to patients, serve as a receptionist to welcome, check-in and alert the medical personnel of appointments, and guide new incomers to the hospitals, triage tasks • Hospital staff can monitor and make requests of robot actions through internet

Kompai [13], Pepper [14], Care-o-bot [15], Sanbot [16] or TIAGo [17] [21] can be used as SAR for assistive tasks, for instance to facilitate communication with family and doctors, and to ensure that frail, isolated or vulnerable people, may engage in other social activities. Thanks to this, doctors can thus interact with patients remotely, and provide education and instructions, without a face-to-face interaction. Users that can benefit most of such robots include older people, individuals with cognitive impairments, those recovering from stroke or related injuries, and children with autism [18], [22]. In fact, SAR used in groups of older individuals have been shown to reduce stress and loneliness, with an overall positive health impact [4], [8] and, in general, acceptability regarding a robot's long-term stay at home [15], [16].

Multiple research projects have focused on SAR. HUMAVIPS (Humanoids with Audio-visual Abilities in Populated Spaces) [18], FP7 CompanionAble (Companionable research project delivers robotic assistance for the older individuals) [19] aimed to provide a companion robot for older people with Mild Cognitive Impairment that helped engage with community. H2020 GrowMeUp [20] highlighted on encouraged independent living while engaging with the community by teleconference. H2020 EnrichMe has tested their robot TIAGo (Figure 1) for monitoring, physical, social and cognitive assistance to older people with mild cognitive impairment, by playing games and giving personalised reminders [23], [24]. By working closely with the target users and their carers the robot design and validation results proved to be highly positive.

B. Healthcare robots and Covid-19

Many of the applications mentioned so far may be of direct use in the situation the world is facing right now - Covid-19 - and some have already been adapted with the aim of

[13] https://kompairobotics.com/robot-kompai/
[14] https://www.softbankrobotics.com/emea/en/pepper
[15] https://www.care-o-bot.de/en/care-o-bot-4.html
[16] https://www.sanbot.co.uk/
[17] http://pal-robotics.com/robots/tiago/
[18] https://team.inria.fr/perception/projects/humavips/
[19] https://cordis.europa.eu/project/id/216487
[20] https://growmeup.deec.uc.pt/

reducing risk of infection and optimising health management. New technologies are becoming of paramount importance in fighting the pandemic, including robots, which can help promote remote human-to-human interactions in order to reduce risk of transmission, lighten the burden on health care providers, reduce loneliness and improve overall health [25].

The SAR role in these situations can be multiple:

- Use of drones by CloudMinds [21] to enforce quarantine restrictions, alerting individuals to return to their homes, deliver medicine to patients with Covid-19 at Wuhan as well as transferring test samples.
- Mobile robots can be used for hospital logistics [22] [23].
- Mobile robots that can sterilize surfaces with UV light such as [26] or Blue Ocean's UV disinfection robot [24].
- Automatic temperature-taking with thermal-sensor equipped robots in public places to quickly screen several people at the same time in large areas, helping to cover screening.
- Social robots that make people less lonely in the presence of widespread quarantine, monitoring them, encourage treatment follow-up and offer reminders, as social distancing can have a negative impact on mental health. Such robots can also help with hospital admissions.

III. Limitations and challenges

While the above mentioned robotic solutions offer exciting opportunities, their deployment in complex real-world scenarios and hospitals is not without its limitations [9]. Andrade et al. [7] identified the main concern to be the high cost of robots, which limits most robot use in research and reduces large-scale robot acceptability studies both with those who manage the robot and end-users. Data privacy issues, which is also a concern for other AI systems such as smart-speakers as well as telepresence robots, may result in individuals feeling uncomfortable about being recorded without their consent. In the context of ethics, robots should be compliant with regulation, and doing a proper risk assessment can be a time-consuming and complex procedure. Aside from these points, human-robot interaction poses several challenges for healthcare [27]:

- Ethical challenges
- Positive user experience
- Cultural differences
- User social acceptance and attitude toward robotic technologies, especially among the older population
- Robot morphology, associated with robot design

In general, a more user-centred design approach would be needed to solve these challenges. Firstly, social robots must be efficient and robust enough to achieve specified goals, for instance [23], by speeding up physical tasks e.g. bringing objects for domestic use. Secondly, social robots in general are still lacking in interaction capabilities. One main drawback in speech interaction with SAR is that so far they have been focused on one-on-one interaction, with limited words or sentences that they can recognise, rather than multi-modal/multi-party scenarios outside the established field [9]. Robots ought to improve their human emotion and activity recognition skills (emotionally intelligent robots) in order to achieve a more expressive interaction and adapt to the needs of each individual, instead of the other way around; especially so that robots can help in psychotherapeutic and home support settings [27]. Safety of all users involved (robot, patient and healthcare workers) must be taken into account during HRI design, by reducing sharp edges on the robot, speed limits, safety distances [27], anticipating potential hazardous situations and responding quickly to new situations via real-time perception of human activity. This is especially important for physical HRI [28]. To improve user experience and acceptance user interfaces should be easy and intuitive for users with different types of needs, by using a combination of verbal and non-verbal communication.

Lastly, it should not be forgotten that robots are just one part of healthcare services, and that for best outcomes they should be well integrated with other medical devices, mobile apps, health records and sensors, and take communities of pharmacists, labs, doctors, and so on into consideration.

IV. The social assistive robot ARI

The newest PAL Robotics' social robot ARI[25] was conceived taking into account the previous challenges. ARI's user-centered design (Figure 2) has been focused on several key considerations: mobility, lightweightness, safety, simplicity and modernity. The major goal has been to improve user acceptability of social robots. both by operators and end-users, by making it more human-like when it comes to both visual appearance and behaviour features such as voice and movement. For this reason ARI has been designed to resemble the human body, on the one hand considering a suitable body-head proportion and degree of iconicity. Secondly, its height has been set to 1.65 cm, the average height of a female adult, adding to it two arms, human-like face and body form. In contrast to related robots in the market it is the one that most accurately mirror humans appearance [29]. Its covers are 3D printed with PA12 to obtain smooth surfaced to reduce risk of injury to people, with a low centre of gravity and low mass of the upper limbs to minimize impact and fall risks.

ARI is provided with a mobile base, torso with an integrated 10.1" Linux-based touch-screen, two arms and a head with expressive gaze thanks to its 2 LCD eyes. It works on Ubuntu LTS, with open source ROS (Robotic Operating System) [26], with an ARI simulator available in Gazebo [27]. It can be configured according to customer needs, facilitating

[21] https://www.dezeen.com/2020/02/20/drones-robots-coronavirus-china-technology/

[22] https://dih-hero.eu/fast-deployment-of-autonomous-vehicles-to-help-hospital-staff-fight-covid-19/

[23] https://www.chinadailyhk.com/article/125077

[24] http://www.uvd-robots.com/

[25] http://pal-robotics.com/robots/ari/

[26] https://www.ros.org/

[27] http://wiki.ros.org/Robots/ARI

integration of external software components. Some of its technical specifications are detailed in Table II.

Fig. 2: PAL Robotics ARI robot

TABLE II: ARI robot specifications

Arm payload	0.5 kg
Hardware max speed	1.5 m/s
Battery life	8-12 h
Computing power	Intel i5/i7, up to 32GB RAM
AI	NVIDIA Jetson TX2
Interfaces	2 x LCD screen eyes with custom animations 2 x 16 GB LED rings in the ears, and a 40 RGB LED back ring 10.1” 1200x800 projected capacitive touch screen
Connectivity	Bluetooth, WiFi, Ethernet

With a high processing NVIDIA GPU and its ROS and REST API, it can be used to develop and deploy powerful AI algorithms, such as deep learning applied to natural language processing, object or face recognition, as well as using reinforcement learning the robot may learn from the interaction, and adapt its behaviour to each user.

ARI’s cameras, such as a Sony 8 MegaPixel RGB camera on the head, and Intel RealSense RGB-D cameras on the front and back of the torso, make it possible to use advanced 3D Perception algorithms and understand the surrounding environment. It is already equipped with some perception packages for ARUCO marker detection, face and people detection as well as planar object detection.

Emphasis has been paid on the design of the audio architecture of the robot, strengthening the robot’s speech interaction capabilities (Figure 3). It has 2 speakers facing to the front and a ReSpeaker MicArray V2.0 [28] microphone array for audio input/output in order to converse using natural language. Audio tests were conducted to verify audio quality, and the covers were modified to include a hole on the front side of the torso, where the array is added with a protective case, which has reduced the reverberation initially detected when the robot recorded its own voice. The ReSpeaker has 4 microphones and was selected due to its feasibility with integration in ROS through the respeaker_ros package [29] and usage of pulseaudio [30] for audio play/recording. For speech interaction, ARI is currently equipped with ACAPELA text-to-speech solutions [31].

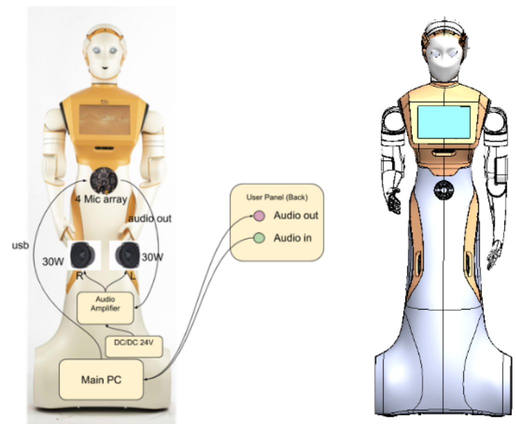

Fig. 3: ARI’s audio architecture.

PAL Robotics has implemented ARI with a Visual-SLAM system for mapping and localization in indoor environments, based on ORB_SLAM [30], which uses ARI’s front torso Intel Realsense RGB-D camera to detect features and perform loop closures when it returns to a previously seen location to update the map of the environment. Through this, after mapping, an occupancy grid map is produced, where ARI can localize in. For autonomous navigation it makes use of ROS’s move_base thanks to which it can avoid obstacles and plan a path to the desired goal. ARI’s SLAM and navigation system may be adapted further by researchers to guide hospital newcomers to their appointments or help the older people with mobility issues around the house. For this purpose, it has 2 differential drive wheels and 2 caster wheels, with a maximum speed of 0.5 m/s respect the hardware maximum speed, limited by obstacle avoidance frequency that needs to slow down autonomous max speed to prevent collision.

It is demonstrated that people are able to interpret humanlike (affective) nonverbal behaviour (HNB) in artificial entities. To express emotion/ empathy a few body cues are used simultaneously mainly: facial displays, body movement and posture and vocal cues.

Ruhland et al. [31] suggests that robots that exhibit such human-like gaze attention, by generating automatic robot facial and body gestures related to the prosodic content, may create stronger feelings from user, improve their understand of the robot [20], making it more predictable, increasing its acceptability and trust. Such gestures can also emphasize what the robot says through words. ARI’s strong point is its ability in providing this multi-modal behavior.

Its LCD eyes with animations, supported by the movement of the head (Figure 4) , enrich the non-verbal interaction

[28] https://wiki.seeedstudio.com/ReSpeaker_Mic_Array_v2.0/

[29] https://index.ros.org/p/respeaker_ros/

[30] https://www.freedesktop.org/wiki/Software/PulseAudio/

[31] https://www.acapela-group.com/

by facilitating the establishment of joint attention between human robot and convey intention, interest and emotions to initiate and respond to the human partner. The design of ARI's slender arms offer the option to show expressive and human-like gestures combined with facial and prosodic features to enrich the interaction. Other cues that ARI can display are changing of the LED colours of the ears or the back torso, to inform about its battery or when it has heard someone speak to it, etc. The LED manager enables robot users to adjust colour, brightness and effects.

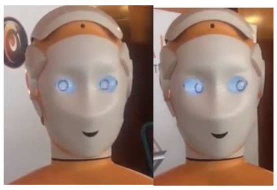

Fig. 4: ARI robot's gaze behaviour

A. *ARI applications as a healthcare assistant and companion*

In the healthcare context, ARI's capabilities could easily adapt to carry out many of the tasks previously mentioned by SAR including hospital reception, patient registration, provide health assessment and also entertain users at hospital waiting rooms or at home. ARI may also be used to remind users to do different tasks, based on monitoring of physiological or behavioural parameters (mood, food intake, sleep), e.g. to take their medication, drink water or eat, suggest social tasks or a specific diet. These are the major applications for which the ARI robot was designed and some of them are in progress even through collaboration projects.

The touchscreen that is fixed on the torso enables ARI to function as a telepresence robot which users can use to communicate with family or doctors without requiring physical contact. It can be used to show entertainment content such as videos, or games, including cognitive games for people with cognitive decline, or to show content that is aligned with what ARI is saying, thus achieving a user-friendly interface for those that may have hearing problems.

ARI is IoT friendly and enables interconnection with smart devices, wearable sensors, mobile phones and other Ambient Assisted Living applications. In the healthcare context, it is suitable for remote monitoring of older patients and post-stroke users at home, and collection of physiological data from wireless temperature or pulse oximeter sensors [32]. The data from these devices can be collected by ARI via Bluetooth or WiFi, and, alongside other data collected through interaction (game progress, etc) resend to a cloud server in order to apply deep learning algorithms that may be used to detect abnormalities and improve early disease diagnosis. Through this connection, ARI can update doctors or caregivers of the patients health and alert them if necessary. Similarly, by deploying human activity recognition algorithms and thanks to its cameras, ARI can be adapted to detect falls or other house hazards (gas leaks, etc. intruders) and trigger alarm.

Face tracking and recognition systems enable ARI to recognise new users that come to a hospital, or identify uniquely each patient in order to provide customised care - suggestions, games, reminders - by accessing their electronic medical records, or identify the role of each person caregiver, doctor, patient. Through emotion recognition algorithms, ARI could detect when a person is in need of attention or bored, in order to initiate contact or adjust the interaction accordingly. Gesture recognition algorithms can be employed, combined with learning by imitation, to deliver a physical therapy session to people with upper-limb mobility problems, where ARI can show a series of arm movements that have been previously taught by a physical therapist and that users need to repeat.

In the context of Covid-19 in particular, ARI can help optimise first hospital care and reduce excessive exposure by medical professionals to ill patients. It can also be added with a thermal camera to take a group of people's temperature from a distance, and provide initial health assessments, thus offering a first triage of possible cases an reducing hospital staff burden. At the same time, it can entertain and encourage social interaction of quarantined users, monitor users both at hospitals and home, or offer telepresence communication.

Some of these applications are already study subjects in the two EU projects where ARI is currently involved, H2020 SHAPES and H2020 SPRING. In SPRING project ARI's skills will be further advanced to assist patients at a day-care hospitals, working on improving the navigation, multi-modal speech interaction, and human behaviour understanding. Audio evaluation and improvement is a core topic in SPRING, where the goal is that the robot can engage in multi-party conversations at a day-care hospital. In SHAPES ARI will serve as a companion robot to support healthy living of older individuals. The robot will work delivering cognitive games as it is enriched by digital assistant, facial and emotion recognition systems provided by partners.

V. CONCLUSIONS

This paper has presented an overview of ARI, the new PAL Robotics' SAR and companion. The work started by highlighting the motivation behind the need for healthcare robots and reviewing the main identified needs of the older people, those with physical constraints and people in isolation due to infectious diseases, and also how SAR can benefit them, to improve hospital care and promote independent living. The ARI robot was conceived and designed to address these demands including a wide range of multi-modal expressive gestures, gaze and personalised behaviour, with great potential to become part of the healthcare community by applying powerful AI algorithms. ARI's expressive eyes enrich its multi-modal behaviour even more. ARI is flexible in design, and its purpose is to create a positive user experience, being a companion offering emotional support. Future works with ARI will be validating it with real users especially to improve the human-robot interface. This effort is already in progress in some healthcare-related collaborative projects (SPRING, SHAPES).

We have seen that although SAR robots have many advantages such as helping reduce emergency visits, healthcare costs, and promoting independent living, while also reducing caregiver burden, there are still some barriers however. These include robot acceptability; the need to redesign hospital management, infrastructure, IT, information flow between care providers and patients; constraints in speech interaction; lack of empathy (emotion recognition). Up until now, real-life applications of SAR for healthcare are emerging and being validated for their deployment, and are still behind logistics and surgery in quantity of deployments. However, over the next few years the adoption of SAR robots will be streamlined with an urgent need, in response to situations such as the COVID-19 crisis, maturing these solutions as they become more relevant. Importance in robot design, being end-user centered, conveying social cues to understand and be understood by humans, and ensuring the robot remains easy to use and deploy, will become increasingly important for SAR in order to turn them into real partners, not just tools - and the ARI robot is moving in this direction.

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