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Responsible Robotics and AI for the Real World

Proceedings of:

INTERNET OF INTELLIGENT ROBOTIC THINGS FOR HEALTHY LIVING AND ACTIVE AGEING:

WHERE WE ARE AND FUTURE TRENDS

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October 14th, 2019

New Delhi, India

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Preface

This book presents the proceedings of the International Workshop on *Internet of intelligent robotic things for healthy living and active aging: where we are and future trends*. This workshop has the purpose of bringing together researchers from different scientific communities either interested in or actively working on the application of ICT and robotics to provide services specifically designed for the elderly in order to enhance their everyday life and be provided with high-quality healthcare services. We believe a multidisciplinary environment is ideal for fostering and promoting this research area because of its fundamentally interdisciplinary nature. To effectively provide useful robotic services for elderly users requires an intimate collaboration between psychologists, sociologists, computer scientists, and robotics researchers.

October 14th, 2019

Filippo Cavallo
Laura Fiorini
Alessandro Di Nuovo
Yasuo Okabe
N. Alberto Borghese

Organization

The international workshop **Internet of intelligent robotic things for healthy living and active ageing: where we are and future trends** took place in conjunction with IEEE RO-MAN '19 - The 28rd IEEE International Symposium on Robot and Human Interactive Communication. The workshop venue was Le Meridien Hotel located in New Delhi, India, on the 14th of October 2019.

Organizers

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Introduction to Internet of intelligent robotic things for healthy living and active ageing: where we are and future trends.

Filippo Cavallo

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Abstract of the talk

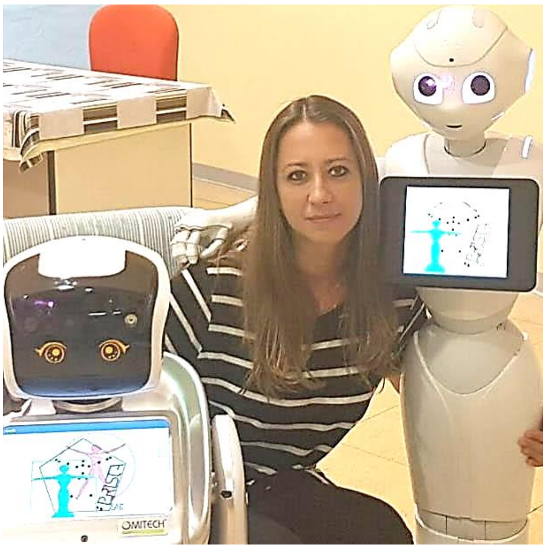
Nowadays ICT and robotic technologies are making available an increasing number of opportunities to be exploited in several scenarios of daily living. Social robotics technologies could exploit this paradigm, addressing capabilities and abilities not only for pure human robot interaction, but also for biomedical applications in the context of assistance, geriatric assessment and stimulation.

Current literature demonstrates that a substantial part of research work in this area is addressing fundamental scientific problem in cognitive human robot interaction, i.e. development of cognitive models for robots and understanding of human mental models of robots. At the same time, cognitive models of social robots deals with treatment of children with ASD or elderly with mild cognitive impairments. In this context, perception capabilities of robots are achieved through emotion, gesture, speech, behavior recognition, achieved with a strong use of various AI machine-learning approaches.

Interestingly, IoT solutions, i.e. environmental or wearable sensors, are designed in combination with robotic developments for exploiting simplification in robot capabilities development, making more information available for the robots and providing data for AI learning based algorithms. Sensors are used for fine biomechanical analysis of movement, combined with artificial intelligence techniques, for example, at the base of creating a framework to objectively quantify motor skills in neurodegenerative diseases and identify challenging opportunities in early diagnosis and therapy control. Similarly, the use of these technologies is also increasing in MCI neuropsychological assessment, for example in the development of tools able to combine physical exercise and traditional cognitive test.

Thus,, the integration of Robotics, Internet of Things and Artificial Intelligence, i.e. Internet of Robotic Things (IoRT) is an interesting approach that enables the possibility to design and develop new frontiers in personalized and precision medicine, cognitive frailty and cooperative robotics.

Invited Speaker



Dr. Silvia Rossi

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Silvia Rossi is currently Assistant Professor at Dipartimento di Ingegneria Elettrica e Tecnologie dell'Informazione - DIETI, University of Naples "Federico II", Italy. Co-chief of the PRISCA (Intelligent Robotics and Advanced Cognitive System Projects) lab. Coordinator and Principal Investigator of the National Projects UPA4SAR "User-centred Profiling and Adaptation for Socially Assistive Robotics", AVATEA "Advanced Virtual Adaptive Technologies e-hEAlth". She received the M.Sc. degree in Physics from University of Naples Federico II, Italy, in 2001, and the Ph.D. in Information and Communication Technologies from the University of Trento, Italy, in 2006. During her career, she was research assistant at the Division on Cognitive and Communication Technologies - ITC-irst (Italy), at the institute of Cybernetics E. Caianiello - CNR (Italy), and visiting researcher at the Center for Human-Computer Communication - Oregon Health and Science University, Oregon (USA). Her research interests include Multi-agent Systems, Human-Robot Interaction, Socially Assistive Robotics, and Recommender Systems. She is Associate Editor for IEEE Robotics and Automation Letters (RA-L), International Journal of Social Robotics, Pattern Recognition Letters, and for Intelligent Service Robotics journal. She is the General Chair of RO-MAN 2020 and is in the program/organization committee of several international conferences on human–robot interaction and multi-agent systems.

Abstract of the talk

A Layered Architecture for Socially Assistive Robotics as a Service: a case study with Alzheimer patients

Socially assistive robotics technology is expected to play a crucial role in supporting home patients. Nevertheless, the adoption of such technology in real home environments is still far to be reached since it presents several challenges mainly related to the possibility of obtaining a continuous situational awareness from ambient devices, the cost-effectiveness of the proposed solution, the flexibility in personalization of robot plans and actions, as well as its acceptance in the everyday life. In this talk, a service-oriented approach developed in the context of the UPA4SAR project will be presented. We propose an architecture for an assistive robotic system that manages different levels of adaptation both at functional level, i.e. determining which tasks can be executed according to the patient's needs and the available technology, and at non-functional level, i.e. determining the modality in which tasks are executed (QoS attributes). Issues and results of the experimentation in real home environments will be discussed.

Prof. Jorge Dias

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Jorge Dias is Professor of ECE Robotics. Professor Jorge Dias has a Habilitation degree and a Ph.D. degree on Electrical Engineering by the University of Coimbra, Portugal (specialization in Control and Instrumentation). Jorge Dias research in the area of Computer Vision and Robotics and has contributions on the field since 1984. He has several publications in international journals, books, and conferences. Jorge Dias was been principal investigator from several international research projects. Jorge Dias published several articles in the area of Computer Vision and Robotics that include more then 100 publications in international journals.The research activities of Jorge Dias have been concentrated in the Artificial Perception applied to Robotics involving international cooperation projects such as CyberMove - Cybernetic Transportation Systems for the Cities of Tomorrow (EC-RTD Project, EVK4 – 2001), VISOR - Visual Perception System for a Social Robot (EURON-European Robotics Research Network) , IRPS - Intelligent Robotic Porter System (EU-IRPS FP6-IST-45048) , BACS - Bayesian Approach to Cognitive Systems (FP6-IST-027140), PROMETHEUS - Prediction and interpretation of human behaviour based on probabilistic structures and heterogeneous sensors (FP7 - 214901) and HANDLE - Developmental pathway towards autonomy and dexterity in robot in-hand manipulation (FP7-2008–231640), Social Robot (FP7 Marie Curie - 285870),CHOPIN - Cooperation between Human and rObotic teams in catastrophic Incidents, TICE Mobility, DIVA – Instrumented Airship for Aerial Surveillance. Since July 2011, Jorge Dias is on leave of absence from University of Coimbra to do research activities on robotics at Khalifa University (Abu Dhabi, UAE). An updated version of current activities is available in the link www.deec.uc.pt/~jorge.

Abstract of the talk

Bayesian User Modelling for situational Awareness Social Robots

One of the key elements of technology acceptance by society is the interaction between artificial and human agents. Unlike smartphones or tablets, where predictability is a requirement, users expect robots to behave more like humans do, and mechanized behavior often demotivates people to continuously use these systems beyond the novelty period. Thus, it becomes necessary for a robot to learn the user's characteristics and continuously adapt its actions to them. This has recently become a trend in the scientific community, which has been endowing robots with the ability to create representations of users using a variety of information.

We are developing a user model, which represents various types of information and uses Bayesian methods to perform inference. The model comprises information inferred from multimodal sources, fusing it into an attribute-based representation of the user. The aim is that a user-adaptive robot can use such a representation to tailor its behavior to the characteristics of the user. This allows the system to automatically exhibit user-adaptive behavior, increasing its levels of interaction autonomy and easing user acceptance.

A modular design approach is followed, where different and independent components process different types of information. This work describes one such module, which aims at inferring over some of the properties that a person exhibits when communicating, such as: How quickly do they speak? How does their facial expression change when reacting to the robot's actions? These properties are inferred from a set of inputs from the robot's sensors, measured while the interaction takes place. The characteristics are labeled using the Big Five traits of personality, which we found suitable to describe these interaction properties. The proposed methodology and parametric instantiation were fine-tuned and validated in simulated scenarios. Additionally, a proof-of-concept test was implemented in a robotic platform that interacts with real users, under controlled conditions, for estimating user acceptance. Despite positive results, the model can still be improved by optimizing evidence selection and applying an adequate parameter learning strategy.

We discuss the integration of this model on a previously-developed framework for generating user- adaptive behavior from a user profile. This integration closes the loop between action and perception, endowing the robot with full autonomy in interaction. We end by discussing the potential impact of the integration of user-adaptive and user modelling techniques to a wider variety of domestic robot tasks, introducing the concept of adaptiveness on a number of previous applications.

Session 1: Chair Presentation

Prof. Yasuo Okabe

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Abstract of the talk

Network platform technology for assistive robots for the elderly by agile co-creation

Abstract

We now have many networked sensors and robots around us, and it is expected that various cloud services using these devices will come out. In a network platform that supports communication among a number of sensors and robots in limited bandwidth, it is necessary to perform explicit network control (priority control, bandwidth allocation, etc.) considering not only the characteristics of the communication of sensors and robots but also the importance of sensors and robots in cloud services, so as to ensure quality of service (QoS). It is also necessary to consider that sensors and robots are shared by multiple people, and that cloud services may change according to the condition of the people who use them.
The goal of the ACCRA project is to define agile co-creation development methods for elderly support systems using advanced ICT robotics, and to demonstrate the effectiveness of the methods. We set three use cases, and are developing applications for them and platform technologies that support the applications. In this talk the architecture of the ACCRA network platform and the technologies deployed in it are presented.

Alessandro Di Nuovo

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Abstract of the talk

Assessment of Cognitive skills via Human-robot Interaction and Cloud Computing

Technological advances are increasing the range of applications for artificial intelligence, especially through its embodiment within humanoid robotics platforms. This promotes the development of novel systems for automated screening of neurological conditions to assist the clinical practitioners in the detection of early signs of mild cognitive impairments. The talk presents the implementation and the experimental validation of the first robotic system for cognitive assessment, based on one of the most popular platforms for social robotics, Softbank "Pepper", which administers and records a set of multi-modal interactive tasks to engage the user cognitive abilities. The robot intelligence is programmed using the state-of-the-art IBM Watson AI Cloud services, which provide the necessary capabilities for improving the social interaction and scoring the tests. The system has been tested by healthy adults (N = 35) and we found a significant correlation between the automated scoring and one of the most widely used Paper-and-Pencil tests. Also, an usability study shown the system was scored very high, among the most usable software products available on the market. We conclude that the system can be considered as a screening instrument for cognitive assessment.

Session 2: Author Presentations

"A Robot in Every Home. Automated Care-Taking and the Constitutional Rights of the Patient in an Aging Population"

Andrea Bertolini, Shabahang Arian

"The MOVECARE platform: Service robots, IoT, Virtual Communities and Smart objects to serve independently living elders"

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The MOVECARE platform: Service robots, IoT, Virtual Communities and Smart objects to serve independently living elders

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***Abstract*—We describe here a heterogeneous platform that integrates a service robot with an IoT network, smart objects and a virtual community, orchestrated by an empathic and intelligent virtual caregiver, to provide monitoring, assistance and stimulation to elders who live alone at home. Key characteristics are being unobtrusive, that allows transparent monitoring possible decline, modularity that allows serving the same functionality in different modalities and pervasivity that allows covering the whole home.**

Keywords—Monitoring, Community Based Activity Center, Cognitive and Physical decline indexes, Service robot, IoT, Smart objects, Artificial Intelligence, Virtual Caregiver.

INTRODUCTION

Population is aging in Western Countries. According to Eurostat [1], the old age dependency ratio, i.e., the ratio of elders (over 64) to the working-age population (15-64 years) of European countries will approximately double between 2015 and 2080 from 25% to 50%. Aging goes hands in hands with physical and cognitive decline that is already having an enormous social and economic impact on the society.

Therefore, ccounteracting elders decline is one of the top priorities of the National Health Systems in the Western Countries and several research and pilot projects have been financed with this aim.

This work has been partially supported by H2020 program under contract Number 732158, Project Movecare: http://www.movecare-project.eu.

We describe here the MOVECARE (Multiple-actOrs Virtual Empathic CARgiver for the Elder) H2020 platform developed to provide elderly users with monitoring, assistance and stimulation to a healthy lifestyle. It is based on the integration of a Service Robot with an IoT (Internet of Things) system, smart objects a Virtual Community and an Intelligent Virtual Caregiver, with a modular approach that allows using multiple devices for the same functionality. Interfaces and interaction modalities have been designed to maximize ease of use. Such platform will be tested next winter on a total of

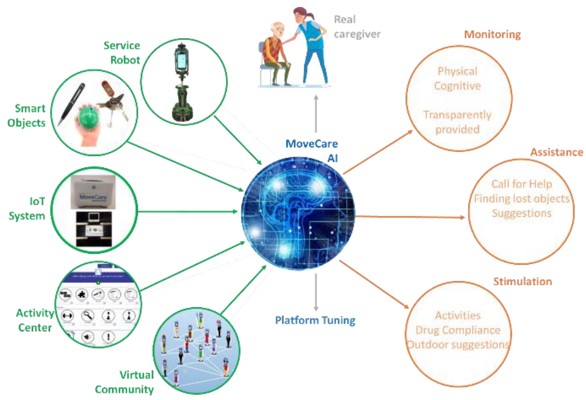

Fig. 1 (the components on the left) and the main functionalities (right) provided by the MOVECARE platform. Please notice that the system continuously monitors and tunes the system through an Intelligent Virtual Caregiver and that real caregivers are inside the loop.

30 elders living independently: 16 in Extremadura and 10 in Lombardia region, and on 4 elders living in private residences offered by Korian.

THE MOVECARE PLATFORM

Main functionalities offered

The main functionalities provided are shown in Figure 1.

The platform has been realized to match the needs elicited from elders themselves through a thorough investigation by means of questionnaires, interviews and focus groups. Cognitive and Physical activities with peers inside a Virtual Community, are proposed by a Community Based Activity Center (CBAC) with the aim of avoiding isolation and maintain a good physical conditions. Monitoring data are acquired through smart objects, IoT system and physical and cognitive activities provided by the CBAC. The Service Robot, besides providing a possible interface for the Activity Center, can find lost objects and calls for help in case of need. Lastly, an Intelligent Virtual Caregiver receives all the data and provides to real caregivers indexes of possible decline and suggestions, and tunes the platform to elder's needs. The following sections describe in more details the components and the functionalities offered.

Service robot

Key functionality required by elders who live at home alone is safety [2]. To this aim, we have developed and integrated a help system that is based on a distributed set of smart microphones and a service robot (Fig. 2). The robot is an enhanced version of the Giraff tele-operated robot developed inside AAL domain [3]. Such robot, named Giraff.X, has a three-wheel support and is able to move independently inside the house and seach for the elder. Navigation is supported by a map of the house that is acquired at installation time [4] and it is based on the integration of 2D lidar information and RGB-D information provided by two cameras. The acquired map is also used to annotate through a graphical interface the position of all the objects in the IoT network at installation time.

Fig. 2. Giraff.X robot on the left. Notice the two RGB-D cameras above and below the screen and the two RF-ID readers at the basis of the neck. On the right a smart microphone and a tagged object (keys holder) are shown. Notice the eyes blinking on the black screen.

The smart microphones are equipped with an advanced Automatic Speech Recognition (ASR) mechanism able to acquire and process voice signal in real time, and recognise a series of commands, mainly help requests, in three languages: namely English, Italian and Spanish. The microphones can be tuned to the voice of each elder and allow picking up only genuine help requests with a reliability close to 100%. In terms of hardware, the microphone consists of a custom designed and developed Printed Circuit Board (PCB), which includes an ARM Cortex-M0 32 bit microcontroller core for signal acquisition and processing and an ESP8266 module which provides WiFi connectivity to IoT network. The PCB also includes a microphone amplifier with Automatic Gain Controller (AGC), to adapt to different voice levels, signal filtering and low-noise microphone bias. The PCB contains also an interface to a speaker that enable notifications to the user. Lastly, the PCB manages also speech acquisition required to fine tune the smart microphone.

The help signal, picked up by the smart microphone, is then transmitted to the service robot, that navigates to the room in which the help request has been detected, looks for the elder and starts a brief dialogue with him/her to confirm the help request. In case no feed-back is detected or the need for help is confirmed, it establishes a video-communication with the remote caregiver, who can evaluate the situation and start the most adequate intervention.

Another key assistive functionality provided by the robot is finding lost objects. This is based on the acquisition and processing of RSSI (Radio Signal Strength Indicator) emitted by tagged object [5]. An RF-ID tag is attached to keys, wallet, TV controller and other objects of elder's choice. Upon elder's request, the robot starts searching for them through the RF-reader that it has on board, until either it found the requested object or it failed the search. UHF tags allow getting target information from 1.5 meters downwards and are therefore suitable to home environment. Indeed, if the object is at home, the success rate is close to 100%.

Particular care has been devoted on robot's interfaces: interaction is mediated mainly by speech dialogues that are the most natural interfacing mean [5]. Speech understanding is implemented in two steps: first the speech is automatically translated into text through Google Cloud Speech API[1]. Key words related to each dialogue instance are then indentified and processed inside the semantic domain of the current particular interaction. To this aim a dialogue manager has been implemented as a UML (Unified Modeling Language) finite state machine that allows taking into account possible development of dialogues related to each robot activity. Speech synthesis produce robot's feed-back to the elder in a harmonical way through Acapela Voice As a Service[2]. Moreover, the design of the screen interface has been refined several times to improve the user's experience and it appears

[1] https://cloud.google.com/speech-to-text/

[2] http://www.acapela-vaas.com/

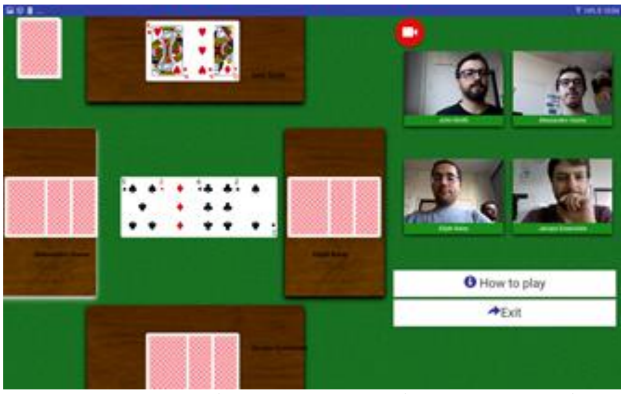

Fig. 3. The client view of the CBAC: on the left the virtual deck of the game (a scopa game in this case), on the right the video streamed of four players, with the control logic on the bottom.

now as a pair of eyes on a dark background that mimics a real face.

Activity Center

A Community-Based Activity Center has been developed to provide the user with cognitive and physical activities that can be performed with peers living remotely in their own homes. The CBAC is inspired to the IGER platform developed to support autonomous rehabilitation [7] and it is an innovative platform that combines a virtual deck on which activities are carried out with real-time streaming of video, picked up by the device web-cam, of users participating to the activities to enable real-time video-communication (Fig. 3). It leverages a client-server architecture where the client provides the current view of the activity to the user as it is received from the server; it can be any mobile terminal with a touch screen: a standard PC, a TV connected to a PC and browsed through a remote TV controller, or the display screen of the Service robot itself. The client sends back to the server the action of the user (tap or drag on the screen, mouse movement, pointing with remote TV controller). The server updates the state of the activity and sends the new view to the Client. The server also logs all the data that can be potentially useful for monitoring and uploads them to a secure data-base on the cloud. Such information can later be used to monitor possible decline.

Cognitive activities provided can be played in a cooperative or competitive way. Each user, in turn, can make his/her move, that is visible to all other users, using drag and drop over a tablet or using a remote controller that allows pointing over the TV screen. While playing the user can chat and discuss with his/her peers. Additional peers can join just to watch the game. Cognitive games implemented are: cards games (scopa and briscola, typical card games that are played in the South of Europe), checkers, puzzle and pictionary. To keep in good physical condition, two video channels are provided in which the elder is guided to carry out gentle exercises by a video of a real-elder. The exercises have been identified by clinicians to improve balance, thus decreasing the risk of falls.

Physical activities are provided through videos and exergames. Two video channels, one for upper body and head and one for posture training, are available; in each channel, the elder is guided to carry out gentle exercises by videos of a real elder. The exercises were identified by clinicians to improve balance, thus decreasing the risk of falls. The exergames can be carried out with the same smart objects used for monitoring (e.g. the anti-stress ball), described in Section D.

Typical data logged from the activities are time before a move, move selected, total duration of an activity and total use time of the platform. Besides this, indicators specific of each activity are also provided. For instance, for card games, the value of each move with respect to the maximum value is logged as a measure of the ability to play. For physical activity, oscillations amplitude during the exercises is logged as a measure of postural stability.

Finally the CBAC supports therapy compliance through a multi-media alarm on the elder's smart phone that, at the right time, through video / animation / graphical instructions to take the prescribed drugs. These alarms comprehend a picture of the box and the number of pills remaining to facilitate the correct posology.

Monitoring

Aim of Movecare is to monitor the elder without asking him/her to change his/her habitudes at all. Therefore we do not ask him/her to wear sensors or other elements but we distribute sensors inside the house objects: monitoring leverage the full fledged set of sensors, activities and functionalities to get am updated picture of the elder's physical and cognitive state.

One pillar of monitoring is constituted of classical domotic sensors integrated inside an Internet of Things sub-network. Such sensors are pressure mats to determine when the user is sitting on the couch or in bed, door entrance switch, PIR (Passive InfraRed motion detector), temperature and humidity sensors and allow the Virtual Caregiver to get a picture of the elder situation and tune the intervention. An additional object aimed to control weight variations is a blue-tooth scale connected to the same network.

More targeted sensors have also been developed, with the aim of monitoring specific quantities. Postural stability is evaluated in normal daily-life activities through the data provided by a pair of instrumented insoles [8] inserted inside

Fig. 4 Three smart objects: a smart ball, a brush and a watering can. Notice the hand of the last two objects has been substituted with a 3D printed plastic handle that

the elder's shoes. The data allow assessing lateral stability in terms of pressure lateral oscillation during free outdoor gait.

A micro-architecture has been developed to measure pressure and motion and transmit it in real-time to a mobile terminal. Such micro-architecture has allowed realizing an anti-stress ball that is used to carry out exer-games measuring grip force at the same time. Smart handles have also been realized: they embed this micro-architecture inside a rubber band ora rubber tube, that can be applied for instance on the supermarket trolley or on a watering can (Fig. 4). In this way the system measures an index of clinical validity, the maximum pressure, in a transparent way.

Monitoring is also carried out through the service robot through a novel concept of administering tests distributed over time. Such tests address mainly episodic and prospective memory, and spatial and temporal orientation, whose decline is strongly related to pre-frailty. To this aim, the Virtual Caregiver commands the robot to ask to the elder a spot question about the recent past, the environment, and common topics. The elder has to provide an answer searching in his/her memory and his/her answer is recorded and automatically analyzed. Few questions per week are provided to avoid being too intrusive.

Another monitoring functionality is automatic processing of voice sampled by the CBAC, the robot or by the elder's smart phone during conversations. The signal is processed on the fly to derive a set of phonetic features with which more than 70% of elders, who have developed dementia, could be identified [9]. Further investigation will allow to increase such figures identifying new and more sensitive features.

Last but not least, classical screening cognitive tests like Bells and TMT-A and TMT-B have been implemented digitally and are administered at home by the service robot. The Virtual Caregiver supervises the tests and guides the elder by means of adequate dialogues. Data on tests execution are stored on the cloud and automatically processed to score the tests. Moreover, the clinicians can replay the test to evaluate if possible decline is taking place. The clinical validity of these tests has been assessed in a recent study that has also highlighted the potentiality to derive additional and finer quantitative indexes to be examined by clinicians [10].

The Virtual Caregiver

As it can be appreciated the Movecare platform is highly modular and comprises a set of heterogeneous components. To coordinate such heterogeneous components, a Virtual Caregiver (VC) has been developed. It analyses the input collectively provided by the monitoring systems, the CBAC, the service robot and it provides recommendations, tunes the activities and the suggestions and provides the real caregivers with warnings.

To maximize effectiveness, the VC has been implemented through a novel mix of sub-symbolic and symbolic reasoning on the heterogenous data that it receives. In particular, classical reasoning allows to react to anomalous data, while sub-symbolic methods based on machine learning allow predicting future evolution on one side and identify in a robust way possible decline, through clustering procedures that work on the data provided not only by monitoring but also by activities themselves. For instance, for physical monitoring, data coming from insoles can be merged by the VC with the data on lateral stability coming from the gentle physical exercises or exergames to derive a clearer picture of possible physical decline.

RESULTS AND DISCUSSIONS

Engagement is a key element for acceptance of a platform such as Movecare. To this aim, elder can choose on which device (tablet with touch screen, PC with mouse and keyboard, Giraff screen or TV with remote control) to perform an activity, according to elder preferences. This technological equivalence is fully supported by a standardization of communication protocols and of interfacing mechanisms.

Another element that can help creating a positive user experience is solving problems, even small, in everyday life. Loosing objects is common and enabling Giraff to locate them for the elder can increase user's trust in the system. Moreover, the ability to provide help in a robust way is another key property. These two functionalities would make the Movecare platform most useful to the elder.

Moreover, a strong social dimension characterizes the Movecare platform. Most of the activities can be carried out with peers through the virtual community, thus making the CBAC a true social engine. Interestingly, of ten elders who took part of one of the pre-pilot rounds, two of them, who did not know each other before, started going out together on a regular basis and became friends. As such, the platform can answer the need to exit from isolation that may be one of the most critical elements of the life of elders who live alone [2]. To further increase socialization, peers with whom to carry out activities, are suggested by the VC, analyzing the profile of the users and their past activities. Through pattern matching techniques applied on elders profile forums, groups and individuals to which the elder may connect are suggested, increasing their engagement in MoveCare. The analysis of the social ties network of users provides clusters of users with similar interests and attitude.

The heterogenous and modular nature of the Movecare platform cannot be detrimental to security. Correct operation of high priority functionalities, like help, is guaranteed under all emergency technical conditions. For instance, if the robot is under charge and cannot reach the elder to establish a video communication, a GPRS telephone call is placed in any case to the real caregiver. We have decided not to rely on intelligent commercial microphones like Alexa as they require a specific protocol to be activated and the elder cannot be in the position to do this and we have resorted on a custom microphone, specialized to this situation and robust against interferences and noise to maximize reliability of detection the help request.

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A plug and play transparent communication layer for Cloud Robotics Architectures

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***Abstract*— Cloud Robotics paradigm aims at enhancing the abilities of robots by using cloud solutions. Over last year, Virtual Private Networks (VPNs) have been often introduced as communication infrastructures. One limitation of this solution is the complexity related to the configuration of each robot in the system, especially for non-technical users. To overcome this problem, this paper demonstrates the functionality of a "plug-and-play" infrastructure for remote control of multiple robots by multiple users based on existing WebSockets technologies. The "plug-and-play" solution is evaluated in both simulated and real scenarios. Perticularly, in the real scenario, three no-expert users teleoperate simultaneously three remote robots by using the proposed communication layer with different networking protocols. Qualitative and quantitative results confirm the scalability, the reliability and the effectiveness of the implemented solution.**

Keywords—Cloud Robotics, System architecture, Remote Control

INTRODUCTION

In the recent years, the constant improvements in telecommunication infrastructures and the recent growth of Cloud infrastructure have led the birth of a new branch of research, namely Cloud Robotics, where cloud solutions are used to enhance the abilities of robots. Cloud Robotics paradigm can be defined as "the combination of cloud computing and robotics" [1].The concept is "not related to a new kind of robot but to the way in which robots access and store information". Cloud robots are recently defined as "any robot or automation system that relies on either data or code from a network to support its operation, where not all sensing, computation and memory are integrated into a single standalone system" [2]. Nowadays, cloud robotics solutions have been implied in different applications. Beyond the specific applications, several works focused on the definition and implementation of the architecture for communication and interaction between physical robots and virtual resources hosted on cloud infrastructure. Different solutions have been provided, but the problem of bi-directional communications among agents (in the specific on the presented work, from a user interface to a mobile robot platform and vice-versa) on different networks is often not addressed or underestimated. Virtual Private Networks (VPNs) are usually introduced as an operative solution to solve visibility issues, but this does not take into account the efforts needed on the configuration of each agent in the virtual network.

The aim of this paper is to describe and test the effectiveness of an approach based on WebSocket communication, reverse tunneling and port remapping according to information stored on a central server. The idea is to provide a "plug and play" solution that does not need further setup work when it is used on a new hardware introduced in the system: in other words, the communication layer should be untied from the hardware in use. As result, it could be easily used in any situation where a robot has to be remotely used from agents (e.g. user interfaces) outside the robot network.

It has to be underlined that the solution described in this paper is still based on configuration methods, as in the case of VPNs configuration, rather than on implementation of new software. The rationale beyond this choice is based on the aim to achieve a reliable system starting from mature technologies already available. The developed solution is proposed to endow the ability of remote control to a set of generic robots controlled using the ROS framework. In this context, rosbridge_server provides a layer that can run on the local machine upon the ROS framework, providing an interface for communications outside the local machine using the rosbridge protocol. Therefore, the problem issued in this paper can be described as the definition of a method to remote control a desired robot (chosen among a not defined set) from a device (smartphone, tablet, laptop, desktop pc), with no restriction on the network's configuration. With this solution, both controlled robot and controlling device can be in different private networks, with no issues related to the lack of visibility between robot and user's device.

SYSTEM DESCRIPTION

The system implements a communication layer for cloud-based robotic scenarios where multiple-users-multiple-robots are present. Due to the variety of technologies involved, interoperability between heterogenous (e.g. smartphone, tablet, laptop) and different kind of robots is required. Besides, the communication mechanism should guarantee real-time performances in order to enhance user's experience with the robot, even remotely. The proposed solution is designed based on the case study with one-user-one-robot described in our previous work [3]. As the architecture presented in [3], the key components of the system are:

- A server, namely a virtual machine hosted on a cloud service infrastructure, characterized by a Static Public IP and that allows Gateway Porting as ssh configuration;
- A robot, based on ROS middleware for local control, and both ROSBridge Server [4] and a ROS Web Video Server [5] running to allow incoming connections on default port 9090 (for ROSBridge Protocol[6]) and port 8080 (for video streaming through video server).
- A user interface, where the user can remotely control the robot through a Web Page running on server and accessible from any device.

With respect to the architecture described in [3], the Cloud resource is a Linux virtual machine running on FIWARE [7], which executes a LAMP server (Linux Apache MySQL PHP). Since multiple agents are involved, a database is implemented on the LAMP server where each robot is mapped to a Port number. The Port number is defined as the MAC address of robot network hardware, since it is a unique information that can be used to characterize it. It is worth noticing that any ROS-based robot can be integrated in the system with no additional changes in the configuration, that represents the flexibility of the system.

Based on this infrastructure, each agent (user or robot) can be in a different private network, while only the server should be reachable from outside. At the robot side, the lack of bi-directional visibility is solved by the SSH reverse tunneling technique, which open the communication between the robot and the server. In this work, the robot automatically queries the database the dedicated ports (for ROSBridge controls and video streaming) related to its MAC address. The user remote control is performed through a Web Page hosted on the public server. The user can select the use of a specified robot and this choice is used to instantiate a ROSBridge Client and a video client pointing to server IP and the ports specified in the database. Therefore, the communication is forwarded through the opened reverse tunneling to the selected robot. Once the communication between the user and the robot is established, the user can send commands to the robot by using web pages stored on the server. By dedicated web pages, the user receives feedback on the requested commands (e.g. video streaming, executing velocity).

EXPERIMENTATION

Two experimentation setups have been developed to demonstrate the reliability and effectiveness of the proposed system. The experimental setups differ from each other based on the number of agents (users and robots), network infrastructure and scenarios. The first experimental setup evaluates the system in a simulated scenario. In details, the agents involved have been approximated with a computer running several ROS frameworks. The second experimental setup recalls a real situation, where multiple users interact with multiple robots. The robots used in this experimental phase are two Astro robotic platforms [8] and one Coro robotic platform [9]. Both robots are based on SCITOS G5 mobile platform (Metralabs GmbH, Germany). They are equipped with a front and rear laser scanner to safely navigate the environment. Cameras for video streaming are also mounted. Astro and Coro platforms implement a *teleoperation service*, which allows a remote user to send velocity commands to the robot and to receive images of the environment where the robot is moving. Both robotic systems are developed based on ROS framework.

TABLE I. NETWORK SPEED SPECIFICATIONS.

Network name	Ping (ms)	Download (Mbps)	Upload (Mbps)
Pontedera (wired)	7	94.41	89.44
Pontedera (wireless)	7	287.77	113.18
Pontedera (4G)	38	7.13	4.97
San Giovanni Rotondo	19	31.13	8.91
Vlissingen	15	80.07	19.36
Peccioli	31	5.41	5.36

This section aims to describe the different setups.

Test1: Simulated environment Open-loop spiral trajectories

The effectiveness of the communication layer has been evaluated based on the experiment described in [10]. The experiment assesses real-time control of motion of Turtlesim robot (default simulator in ROS) following an open-loop spiral trajectory. A spiral trajectory is defined as a combination of an increasing linear velocity over time and a constant angular velocity. Speed commands have been remotely sent from 5 machines (users) to 5 different machines, each one running a Turtlesim robot, through the described architecture, using the server on FIWARE. Since spiral trajectory is sensitive to delays and jitters, the final pose of simulated platform has been used as qualitative metrics to evaluate real-time performances, namely the variability of the received commands along the path. Test1 has been repeated 10 times, each time using 5 couples of user-robot.

Test2: Qualitative evaluation of simultaneous teleoperation

While previous setup is performed in a simulated scenario, Test2 involves the presence of real robots. In details, a remote teleoperation has been evaluated on 3 users simultaneously controlling three different real robots. This experiment extends the results already obtained in [3], where only one-user-one-robot was considered. The analysis of performance in varying image resolution has been computed, since received speed commands have been evaluated in Test1. Namely, the image quality rate is tuned ranging from 90% to 50%.

During the test, the operators are located at the BioRobotics Institute in Pontedera (PI, Italy). By using their own laptop, they access to the corresponding web page to teleoperate the assigned robot, which is located in a remote area. Namely, one Astro Robot is located the Ospedale Casa Sollievo della Sofferenza in San Giovanni Rotondo (FG,Italy), another Astro robot is situated in WVO Zorg Ter Reede residential care center in Vlissingen (ZE, Netherlands) and a Coro robotic platform is located at the Assistive Robotics Lab in PeccioII (PI, Italy). Fig. 1 shows the experimental setup. While every robot is connected to the Wi-fi network of the building where it is located, each operator accesses to the web interface by using a different network

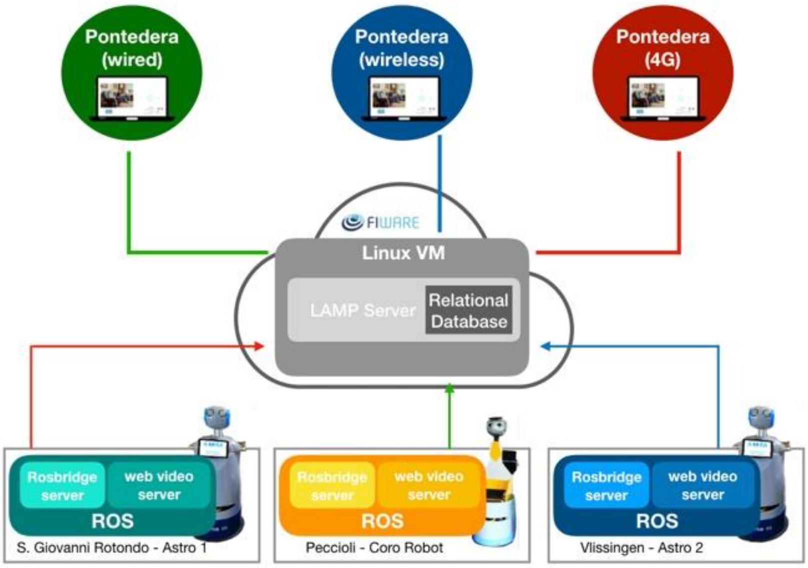

Fig. 1 Experimental setup for Test2. The association between user and robot is identified by the color of the arrows.

technology: an Ethernet cable (wired), the Wi-fi of the building (wireless) and a 4G router. Network speed specifications have been computed using SpeedTest by Ookla website[3] and they are reported in **Errore. L'origine riferimento non è stata trovata.**. The metrics used to evaluate the performance are: the average packet size, the throughput relative to different packet sizes, expressed in packets per second (pps), and the average delay between consecutive received packets at the teleoperation center. The evaluation metrics have been computed by analyzing the http packets received at the teleoperation center on the dedicated port, by using WireShark tool[4].

RESULTS AND DISCUSSION

The results obtained in the two test scenarios demonstrate both the reliability and the feasibility of the "plug-and-play" system. The results of Test1 were obtained by analyzing the final position of the simulated robot at the end of the open loop in the overall 50 tests (Test1 has been repeated 10 times, each time using 5 couples of user-robot). Results shown that the proposed architecture is able to transmit open-loop commands, introducing a negligible variability σ_x= 0.001m, σ_y = 0.004m over a path long 78.275m. With respect to the results reported in [10], the trajectories are correctly accomplished following spiral trajectories. The performance is not influenced by the presence of delays and jitters at communication layer, which caused misbehaviors in [10], as shown in Fig. 2.

The quantitative results of Test2 have been collected by measuring the video streaming parameters during the teleoperation. In details, five teleoperation modes have been tested, each of them characterized by a different encoding quality of the image. A comparison between the packet sizes received by each operator at the teleoperation center is shown in Fig. 3. As expected, the packet size decreases as the resolution of the image sent by the robot camera decreases. The average (μ) pps exchanged by FIWARE and the operator is almost stable (μ_{th}=29 pps and σ_{th}=0 pps for wireless connection, μ_{th}=20,60 pps and σ_{th}=2,41 pps for 4G connection), except for the experiment involving Coro robot (and wired connection), in which the pps varies significantly according to the image resolution (μ_{th}=10,80 pps and σ_{th}=4,55 pps). As shown in Fig. 4, the most significant delay were perceived on the 4G connection's case (up to 190ms).

The rationale behind the development of the proposed architecture for cloud robotics relies on the need of a reliable solution that allow the inclusion of new agents in the system without any specific configuration on the local machines. The term "plug and play" refers to the two main features of the system. First, a new robotic platform can be easily integrated in the system by adding a new record in the database. This strategy allows non-technical users to easily change the system configuration and it can be performed also remotely. The second feature regards the types of technical elements involved in the architecture. The development relies on mature and dependable technologies, such as LAMP servers, WebSockets, SSH reverse tunnelling, ROSBridge protocol and server. With respect to the other approaches in the state of the art, bi-directional visibility issue has been moved to a "configuration problem" rather than an "implementation problem". Due to the introduction of ROSBridge technology, no new code or communication protocol was introduced to deal with the presented issue. The experimentation and results reported in the previous Sections confirm the reliability and effectiveness of the proposed solution. Few limitations have to be highlighted:

- Every communication passes by a central server, in a typical network architecture star topology. This leaves to the limitation that the sum of the bandwidth of all communication has to be smaller than the maximum server bandwidth;

[3] https://www.speedtest.net/

[4] https://www.wireshark.org/

- In the presence of robot reboots, the SSH tunneling is interrupted at robot shutdown and it is restarted after robot startup. This requires that on the server the port has to be released in this interval of time.

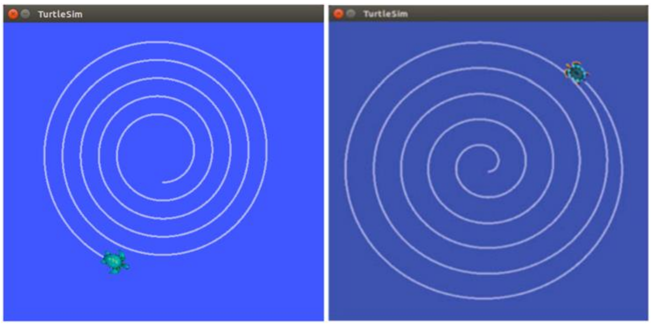

Fig. 2 Visual comparison between spiral trajectories performed in open loop using the proposed architecture (on the left) and obtained through the ROSLink protocol (on the right)[10].

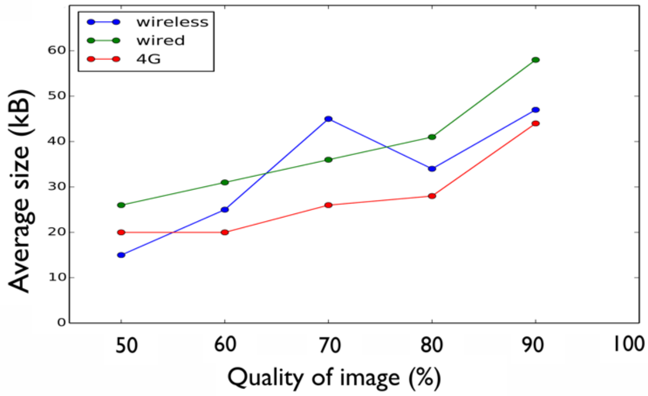

Fig. 3 Comparison between average packet sizes received at the teleoperation center.

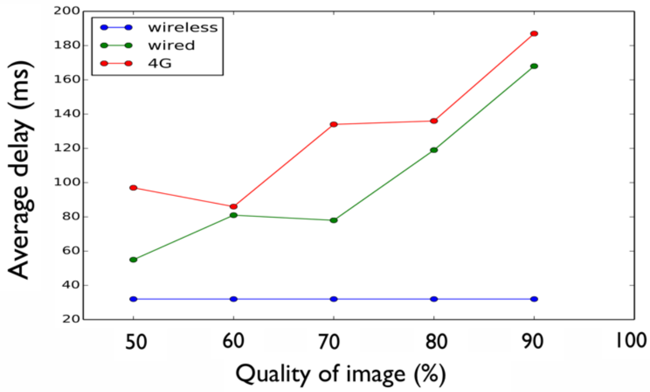

Fig. 4 Comparison between average delays of two consecutive packets at the teleoperation center.

Conclusion

The aim of this paper is to describe and evaluate an approach for cloud robotics system in order to overcome issues on bi-directional visibility. Even if VPNs represent an effective solution, their implementation requires specific interventions and configurations for each agent involved in the system. This kind of activities requires the involvement of technician or experts. The system proposed offers a "plug and play" solution, in the meaning that configuration is automatically retrieved from a public database and reverse tunneling allows any kind of protocol for local connection (local Wi-Fi, public Wi-Fi, mobile 3G/4G, etc.).

The main contribution of this work is to facilitate the setup operations needed to install a robot system in a real scenario (outside the lab environment). Moreover, in the specific case of mobile platforms, a robot can travel among different Wi-Fi networks in a large area: the proposed solution avoids managing particular configurations for each network, basing the communication on a public resource. The developed system is based on mature technologies that allow achieving encouraging results on reliability and feasibility for remote control applications. The results of Test2 show that the three operators are able to simultaneously control the three robots without experiencing any significant delay able to corrupt their performance. Few limitations arise, mainly related to server performances on ports management and network architecture star topology. In conclusion, a deeper introduction of already developed technologies in the context of cloud robotics can hardly enhance the readiness of technology, in particular by providing solutions that can reduce the needs of interventions of expert users or developers.

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Living with *Buddy*: can a social robot help elderly with loss of autonomy to age well?

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***Abstract* — In line with the successful aging models, a preliminary qualitative study with phenomenological interviews was implemented with 40 elderly individuals and caregivers. Complementary results from 8 cocreation meetings allowed us to prioritize the robotic functionalities to be improved and determine the added value of robots in comparison with those of other IT solutions. An experimentation has been launched and is still ongoing with a domestic social robot with elderly. In this paper, we highlight the specific role that robots can play in facilitating aging adjustment strategies.**

***Keywords* — Social Robot, Aging Well, Co-creation, Companion, Elderly**

I. INTRODUCTION

Many countries are currently facing the challenge of an aging population because of the increase in life expectancy and the aging of the baby-boom generation. The aforementioned implies providing care to a growing number of elderly individuals whose health tends to physically and cognitively decrease over time, while many countries cannot face the lack of professional caregivers. New issues are emerging around the concept of Desired Aging Well [1] and with the problem of taking care of elderly individuals with a loss of autonomy in their homes or in noncaring residences. Developing new solutions to help elderly individuals on a daily basis therefore has become imperative. Within this context, technical innovations can help better monitor elderly individuals in their everyday lives or remotely assist them, specifically for those suffering chronic diseases [2]. Robotic solutions can help fill the gap between the growing needs in healthcare and the services that occidental countries can provide today. Hence, many companies are interested in this market and in the elderly. This target population has been misunderstood both in terms of the needs to meet through technological innovations and in terms of the environment (stakeholders and living areas) within which these innovations are implemented [3]. The goal of this paper is to understand the perceived benefits of robotic solutions by the elderly individuals with a loss of autonomy who wish to age well.

II. LITERATURE REVIEW

The well-being of elderly individuals and their networks of caregivers can be enhanced by social robots. These robots can diminish their feelings of loneliness and isolation [6]. Nevertheless, elderly individuals and their caregivers seem to be reluctant to adopt robotic solutions [7]. Even if divergences can be noticed, this reluctance is a key challenge to overcome [3]. Our research question is thus to understand the perceptions of elderly individuals with a loss of autonomy towards robotic solutions in an Aging Well framework.

A. Elderly and robots

The global literature reveals a rather positive view of technological innovations in people over the age of 50. Little research has been conducted on the acceptance of robots by elderly individuals with a loss of autonomy: samples are often composed of younger elderly individuals under 65 years of age. Nevertheless it has been shown that the more elderly individuals want to grow old autonomously, the more they will be inclined to accept new technologies to stay home as long as possible [8]. However, despite these encouraging perspectives, elderly individuals are distrustful regarding certain potential negative consequences of these technologies. Robots can give elderly individuals the impression of being permanently watched while the individuals do not want to be treated as children and dislike being supervised [9].

At least, even if elderly individuals are open-minded and are hopeful of robotic solutions, they do not forget the downsides: stigmatization, isolation because of the use of a robot and communication via virtual networks, and dependence on technology [10]. The role of a third party – the caregiver or health professional – can provide confidence to elderly individuals and contribute to an improved perception of the robot. All of the divergences identified in the literature have assumed needs that are largely not being satisfied with today's robotic solutions.

B. The use of robotic solutions in the Aging Well framework

Our research lies within Baltes and Baltes' successful aging model [4]: successful aging stems from the implementation of effective aging adjustment strategies where the individual optimizes and compensates for the losses and gains associated with aging. To question how more specifically robotic solutions can contribute to the well-being of elderly individuals with a loss of autonomy, we used the concept of Desired Aging Well which refers to the psychological, physical, social and financial objectives of aging well and can be conceptualized, within the SOC model, as the selection of aging-related objectives [1]. Ultimately, this article raises the question of whether robots can contribute to optimization and compensation strategies aimed at achieving the seniors' Desired Aging Well (i.e. the selected objectives they pursue in the quest for aging well).

III. Research Methodology

Our study was implemented within the European research project Agile CoCreation of Robots for Aging (ACCRA). The objective was to provide robotic solutions to fulfill the needs of elderly individuals coping with a loss of autonomy, in France, the Netherlands and Italy. The methodology adopted consisted of 4 steps: needs analysis, cocreation, experimentation and sustainability analysis. This paper focuses on the three first steps implemented in France and in the Netherlands. This study was conducted using the robot Buddy, which was under development and was made available by a robot developing company (Blue Frog Robotics).

A. First step: Needs Analysis

Three baseline scenarios were helped guiding the needs analysis and were based on nursing need theory [11] and on a needs classification for day-to-day activities: need for detections, reminders and notifications of situations; security needs (prevent, detect, and alert in case of danger); communication, entertainment and esteem needs.

Phenomenological interviews were conducted in France to determine the needs. Two types of people were selected: elderly between 65 and 91 years old with a loss of autonomy (assessed by the AGGIR multidimensional scale), half of whom living at home and half in senior residence, and who were not mentally impaired; and professional and informal caregivers. In France, 10 elderly individuals and 10 caregivers were interviewed, with a total of 40 semi-structured interviews for France and the Netherland, which were recorded and fully transcribed and analyzed with a thematic content analysis.

B. Second step: Co-creation phase

The purpose of this second step was to develop robotics solutions in close collaboration with the end users and caregivers. Although we followed the cocreation for use/cocreation for others approach guidelines [5].

Eight cocreation meetings were held in the Netherlands and France (4 in each country). For each session, 8 elderly individuals and 4 professional caregivers participated. From the ACCRA consortium, 2 researchers, a care organization manager and 4 engineers (robot developers) attended each cocreation session. Each cocreation session lasted approximately 4 hours and was recorded and fully transcribed. Inputs for robot improvements were noted on a board and were viewable by all participants.

C. Third step: Experimentation

The experimentation phase, which is still ongoing, allows elderly staying at home to use individually the updated robot (Buddy) for three weeks at their place. Some of the elderly participated to the previous research steps. Two phenomenological interviews were led at the elderly's place with each elderly during the three-week experimentation. This helped figuring out if there were any difference in the elderly's perceptions towards the robot during the three-week period. The robot's functionalities and practicability were both assessed during one to two-hour long interviews. At the end of the experimentation, the elderly had to tell if they were satisfied with the robot and if they would like to keep it.

From now on, 10 elderly individuals have been interviewed and observed with the robot at their home in France. At last, 20 elderly individuals will be experimenting the robot in France. It will be tested afterwards in the Netherlands.

IV. Results and implications

While the two first research steps highlighted the enthusiasm of the elderly, the experimentation results stressed elderly's had high expectations and needs about the robot. From now on, this research points out the elderly's very specific needs and the importance of security needs (in case of a fall, they need the robot to help them and call the emergency or their relatives). These security needs must be fulfilled prior testing the robot's other functionalities (communication, companion, etc.). Fulfilling elderly's security needs appears as a necessity even though it may not be a sufficient condition for them to accept the robot. Interacting with a social robot can be considered by them as "fun" and "cute" and can contribute to their enjoyment, if their security needs are already fulfilled. This research points out that positioning the robot is a crucial task that may contribute to the robot's acceptation: elderly would prefer an assistive social robot, which could help them in their daily life.

The experimentation and its analysis are still going on in France and will afterwards be set in the Netherlands. A cross-cultural quantitative survey is also ongoing and can shed light on elderly's needs, perceptions and adoption intentions of the robot. The results will allow to implement the robot in order to fully respond to elderly's specific needs.

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Toward Internet of Intelligent Robotics Things for Active and Assisted Living: Trends in Standardization

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Abstract — **This paper presents some of the advances in the current efforts for standardization of autonomous robotic systems. We will focus in the knowledge representation aspects by referring the concept of ontologies and some examples of how this knowledge representation approach is being used in robotics. Additionally, this paper describes an example of adaptation of the standard IEEE 1872-2015, focusing on the example of developing ICT and robotics to provide services specifically designed for the elderly in order to enhance their everyday life and be provided with high-quality healthcare services. The results in this paper will contribute for the use case focusing in the Active Assisted Living application domain that is currently under development by some members of the IEEE AuR working group. In the future, we expect to integrate the proposed knowledge representation in robotic platforms that were developed to realize such use cases (e.g. GrowMeUp) and promote such standardization efforts in collaboration with relevant European research and innovation networks (e.g. LIFEBOTS Exchange, Digital Innovation Hubs for Robotics).**

Keywords — Robotics, Standards, Active Assisted Living, Knowledge Representation, Autonomous Systems

I. INTRODUCTION

Nowadays robots are moving from structured to unstructured environments, to work closely with humans in daily real world tasks. Examples can be seen in mainly in land robots but also in aerial and marine robotic platforms. Along last years these robotic platforms have been concentrated in autonomy for autonomous navigation for applications such as, transportation, infra-structures inspection or surveillance. Nowadays the applications where the robots are acting as robot companions, extending the human capabilities and providing services to humans became a key development for smart environments. In such application scenarios, the capabilities required to deliver Human-Machine Interaction functionality motivate the integration of features associated with several technological challenges, including active perception features, mobility in unstructured environments, understanding human actions, detect human behaviours and predict human inten- tions, access to large repositories of personal and social related data, adapt to changing context. These features are paramount for applications in the field of Active and Assisted Living (AAL), where the primary goal is to provide solutions that help people through ageing, by promoting active and healthy living. In spite of the sophistication of individualized solutions, there is still a lack of standardization in Robotics and Automation (R&A) field in terms of the way some core components are implemented and this acting as one of the barriers that is preventing robotic solutions for AAL from increasing their technological maturity. Specifically, the approaches used to represent knowledge in such robotic solutions. This paper presents the work in-progress developed by one of the sub- groups working in standardization of the knowledge repre- sentation used in robotics. The IEEE Autonomous Robotics (AuR) working group aims to extend the Core Ontology for Robotics and Automation (CORA) to represent more specific concepts and axioms that are commonly used in the Autonomous Robotics. Therefore, AuR is performing a wide study in different Robotics and Automation (R&A) domains (e.g. flying robots, mobile robots, field robots, marine systems) to identify the basic components in terms of hardware and software that are necessary to endow a robot (or a group of) with autonomy, i.e., endow robots with the ability to perform desired tasks in unstructured environments without continuous explicit human guidance. As a long-term goal, AuR targets to create a standard ontology that specifies the domain knowledge needed to create autonomous systems comprised of robots that can operate in the air, ground, and underwater environments. Additionally, this group is setting up several use cases to validate the standard, which include also AAL application scenarios.

II. ONTOLOGIES

Knowledge models constitute the basic component of knowledge-based approaches in fields such as artificial intelligence (AI) and robotics. According to [1], until recently, there was a tendency to develop knowledge models that represent the knowledge in a way most suitable for performing a given task. As a consequence, the resulting knowledge models were characterized by high levels of arbitrariness, low potential for reuse in other tasks, and low agreement with other knowledge models, undermining semantic interoperability. However, the high cost of developing knowledge models motivated the development of reusable knowledge models. Moreover, the necessity of cooperation among different stakeholders motivated the development of knowledge models that represent a common view of the reality. Due to this, in the last years there has been an increasing adoption of ontologies, since they are built for meeting these requirements.

In general, an ontology is considered as a formal and explicit specification of a shared conceptualization [2]. According to this view, the conceptualization specified by an ontology includes the concepts related to the types of entities that are supposed to exist in a given domain, according to a community of people. The concepts in an ontology are, in general, the concepts that are shared by most of the community. Thus, we can say that an ontology captures a common understanding, or the consensual knowledge, about the domain. Due to this, ontologies can be used for promoting the semantic inter- operability among stakeholders, because sharing a common ontology is equivalent to sharing a common view of the world. In addition, it is important to notice that, in an ontology, the specification of the conceptualization should be formal and explicit. This means that it is necessary to specify explicitly the meaning of the concepts that are included in an ontology, and this specification should be performed in a formal way, i.e. in a machine processable way. This ensures that the meaning of every concept should be rigorously specified and can be analyzed by humans and machines. Moreover, it is important to notice that, in general, ontologies capture the knowledge about the domain in a way that is independent of the task that would use this knowledge. Due to this, ontologies can also be viewed as reusable components of knowledge.

In the next sections, we present an overview of some examples that developed ontologies for robotics and introduce the standard IEEE 1872-2015 that proposes the Core Ontology for Robotics and Automation (CORA)..

A. Robot Ontologies

In the particular case of robotic systems some authors presented some works dedicated to represented relevant information models using ontologies.

Weihong et. al. in [3] applied an ontological approach into solving the problems of semantic heterogeneity of information in decision-making systems for maritime search and rescue ap- plications. In this paper, maritime search and rescue decision- making ontology reference model was proposed. They de- signed an ontology for classification on maritime perils as an example to illustrate the process of ontology description based on Protégé. In contrast to traditional knowledge-based approaches, e.g. formal specification languages, ontology seems to be well suited for an evolutionary approach to the specifi- cation of requirements and domain knowledge.

Moritz Tenorth and Michael Beetz in [4], [5] presented KNOWROB, which combines static encyclopedic knowledge, common-sense knowledge, task descriptions, environment models, object information and information about observed actions that has been acquired from various sources (manually axiomatized, derived from observations, or imported from the web). It supports different deterministic and probabilistic rea- soning mechanisms, clustering, classification and segmentation methods, and includes query interfaces as well as visualization tools.

Keshavdas et. al. in [6] demonstrated a method for the interaction of a robot with 3D landmarks in a search and rescue environment, based upon ontological knowledge, both pre-existing and additionally computed, as an aid to collaborative efforts by human-robot rescue teams. They performed experiments on some car models and robot configurations and found that poses thus generated by the functional mapping workflow perform far better than those by a naive algorithm of the ontological knowledge. In the future, they plan to perform experiments with a navigating robot, with a camera on a movable arm and plan trajectories around several crashed cars that optimize the amount of visualization inside these cars. Further, they plan to extend the notion of openings and containers to other use cases e.g., entering a hole into a room of known dimensions, climbing a known stairway and so on.

B. IEEE 1872-2015 and CORA

IEEE RAS ORA WG [7] worked from 2011 to 2015 to develop a set of standard ontologies in robotics and automation (R&A). Its work resulted in the 1872-2015 - IEEE Stan- dard Ontologies for Robotics and Automation, approved by members of the community. IEEE 1872-2015 defines a set of ontologies aimed at formalizing some central notions in R&A. The main ontology in this set is CORA which specifies concepts and relations that are core to the whole field [7]–[10]. One of its objectives is to serve as a basis for future ontology- development efforts, such as the one described in this article. CORA was founded in the Suggested Upper Merged On- tology (SUMO) [11], a top-level ontology providing some el- emental notions such as physical object, process, and regions. Its development is drawn heavily from methodologies based on formal ontologies, such as ONTOCLEAN [12]. CORA has three major concepts to describe robotic entities: robot, robot group, and robotic system. In CORA, a robot is essentially an agentive device that can act on its own or under control of another agent. CORA tries to be as inclusive as possible in what can be considered a robot; it refrains from defining sufficient conditions for robot. A robot group is a “group of robots organized to achieve at least one common goal.” This concept generalizes entities such as robot football teams and complex robots formed from many individual robots. Finally, a robotic system is a system including robots and a supporting environment.

IEEE 1872-2015 also includes three other ontologies:

- **CORAX** — defines some notions that are useful for R&A, but too general to be included in CORA, such as design, physical environment, interaction, etc.;
- **RPARTS** — defines the different roles that component parts might have in a robot;
- **POS** — defines general notions associated with spa- tial knowledge (position and orientation represented as points, regions and coordinate systems)

III. WORKING TOWARD STANDARDIZATION

In the beginning of 2015, the IEEE-RAS Ontologies for Robotics and Automation Working Group (IEEE ORA WG) published the IEEE 1872-2015 standard, the first-ever standard elaborated by the IEEE Robotics and Automation Society. This standard defines a set of ontologies related to Robotics and Automation (R&A), chief among those being the Core On- tology for Robotics and Automation (CORA), which specifies the main and most general concepts and axioms that permeate the R&A domain. Due to the importance of this achievement, in December of 2015, IEEE ORA WG was the recipient of the *Emerging Technology Award*, a prize given annually by the IEEE Standards Association[1].

IEEE ORA WG started as a study group in early 2011, and became an official working group in November of 2011. It was comprised of several members from a cross-section of industry, academia and government that represent over twenty countries. Since the beginning, IEEE ORA WG was divided into different subgroups which were each in charge of studying a specific R&A subdomain, like Industrial Robotics, Service Robotics and Autonomous Robotics. Even having all these subgroups, all efforts were concentrated in the CORA devel- opment. Currently, after reaching this big step, these subgroups are focusing their activities in their respective subdomains.

A. Advantages of Adopting a Standard Ontology

Creating a standard ontology in Autonomous Robotics will have a huge impact directly or indirectly on all R&A domains. The main benefit of a domain ontology is to set standard definitions of shared concepts identified in the requirement phase as well as to define appropriate relations between the concepts and their properties. Well-founded ontologies embed the domain terminology in both semantic and logical frameworks, which allows one to build a formal theory of the domain. This theory provides a much harder limit to the possible interpretations of the terms in the domain, constituting a preferable tool for standardization work than simple lists of term definitions written in natural language. Furthermore, an ontology may serve further purposes. In the tradition of symbolic Artificial Intelligence, a domain ontology provides a clear set of symbols to be used in reasoning mechanisms for autonomous systems, such as classification, inference and planning. The domain structure encoded in ontologies may provide the blueprint for APIs in domain-specific software packages, or the model for databases. Another relevant use of ontologies is in agent communications, where it provides vocabulary and clear semantics. For instance, future unmanned systems will need to work in teams and communicate with other unmanned vehicles to share information and coordinate activities. There is an increasing demand from government agencies and the private sector alike to use Unmanned Aerial Vehicles (UAVs), Unmanned Ground Vehicles (UGVs), and Autonomous Underwater Vehicles (AUVs) for tasks including homeland security, reconnaissance, search and rescue, surveillance, data collection, and urban planning. A standard ontology in Autonomous Robotics is the right tool that provides the underlying semantics of the vocabulary employed in problem solving and communications for such heterogeneous autonomous systems.

IV. CASE STUDY FOR THE INTERNET OF INTELLIGENT ROBOTIC THINGS FOR ACTIVE AND ASSISTED LIVING

CORA and other ontologies in IEEE 1872-2015 are too broad to be used directly in any system implementation. Roboticists and ontologists are expected to extend them in specific application domains. In this paper we refer to an example of such adaptation, focusing in the application of artificial social companions for Active and Assisted Living.

A. Scenarios of use for Autonomous Social Companion (Social Robot)

In this scenario we aim to conceptualize the way the ontology standard could be used by an autonomous social companion to use a standardized knowledge base and use it during runtime to infer some macro behaviours. Note that this refer to long-term static knowledge and should not be confused with using ontologies to store raw data from sensors, or temporary data generated by any reasoning process. In H2020 project GrowMeUp[2], we can find a publicly available set of user needs and user requirements that inspired us to define the following decription for scenario of use:

Persona: George is an 81 years old man having some light memory problems and also some difficulties in balancing by walking used to stay alone at home. After a fall, during the night, George decided that it was better for him to stay in an elderly care centre since the only person who could take care of him was his daughter, who lives far away in another city, and he is not a very communicative person to ask for support from his neighbours.

User Scenario: In the elderly house one morning George decided to walk to the small, sunny and warmer living room instead of going to the big and colder one at the main entrance. SocialRobot identified him sitting there alone, and ask him if he would like to tell his friend Kostas to join him. George responded that yes, he would like to have his friend Kostas around. SocialRobot went around the elderly centre and found his friend Kostas, a 78 years old man who has similar disabilities and behaviour ways as George. Both became friends in the elderly care centre. SocialRobot asked Kostas if he wants to join George in the small living room because he is sitting there alone. Kostas answered yes and SocialRobot accompanied him in the small sunny living room. George and Kostas were happy to be together discussing and enjoying the sun. SocialRobot recorded that they both like this room and next time it will inform them again, if it finds one of them sitting there alone.

Gherkin Scenarios to describe Use-Cases

Feature: Person Detection and Face Recognition In order to identify the different people around the elderly center As a SocialRobot I need to perform face recognition, while moving around

Background: Given SocialRobot moves around the elderly center and the light conditions will be different in distinct divisions of the building.

Scenario: Person Detection and Face recognition in dimmed light Given the robot is moving around detecting people using the haar like features algorithm And the robot is crossing a division with ambient light below 200-350 luxes. When the robot selects hog like features algorithm to detect people in its way And the robot selects haar like features algorithm to detect faces And the robot selects eigenfaces algorithm to identify the person Then the robot should identify the person.

Feature: User-Adaptive Guided Visit In order to guide a user on a visit to a new location As a SocialRobot I need to move between pre-defined points, while recognizing user characteristics and adapting to them.

Background: Given SocialRobot is standing on a fixed point and is running a person detection algorithm And starts an interaction when a new person is detected in its vicinity.

Scenario: Adaptation to Proxemics Given the user feels the robot is invading their personal space When the robot has determined that the user is uncomfortable with its position. Then the robot should update its model of the user And adapt its positioning accordingly.

Scenario: Adaptation to Hearing Impairment Given the user feels that they cannot hear the robot correctly When the robot has determined that the user is not hearing it correctly. Then the robot should update its model of the user And adapt its speaking volume accordingly.

B. Extending the standard with domain specific concepts

In [13], [14], we proposed a knowledge model using an ontology for capturing concepts related to the person, environ- ment, physical interaction, social interaction, machine/robot interaction and algorithms. The set of concepts proposed in our model extends the Core Ontology for Robotics and Automation (CORA ontology) [8], [15], [16]3, adding the con- cepts related to the context-based human-machine interaction framework in [14], [17].

The knowledge model, in Figure 1, captures the relevant information involved in the human-robot interaction process. We define the upper ontology for this framework based on four main entities: *Machine*, *Human*, *Interaction* and *Context*. From these entities, we can define other entities as associated sub-classes and establish relationships between entities that encode the semantics of their associations. A more detailed representation is explained in our previous work [13], [14], [18], of which we provide an updated iteration resulting from the current experimental application [5].

The entities defined and their relationships allow for the representation of the components of the system involved in

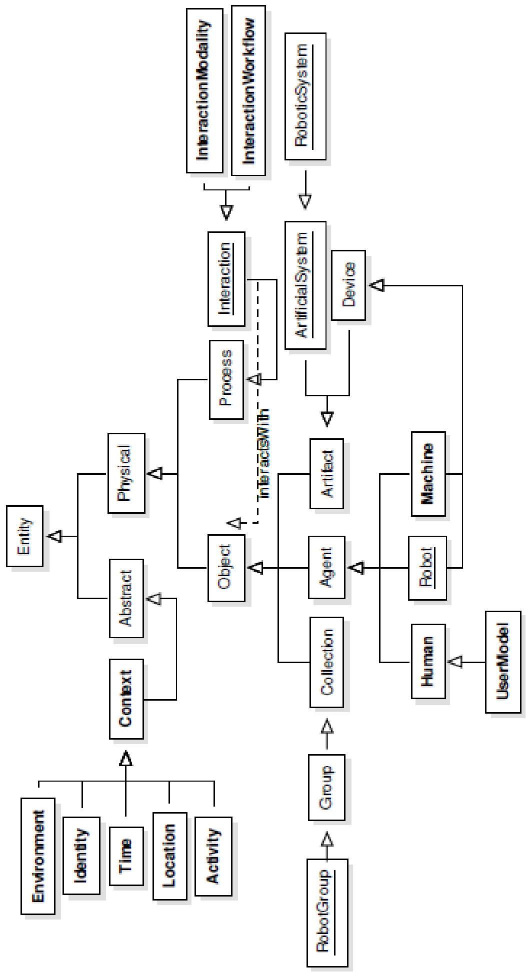

Fig. 1 Knowledge model used in the Context-Aware Human-Robot Interac- tion (CAHRI) Framework extending CORA.

the interaction process at each time.

In addition to defining classes' taxonomy, we define Object Properties (OP) and Data Properties (DP) that will establish the relationships between individuals of each class. Our current model includes the following object properties:

- (OP) hasActivityMission
- (OP) hasActuator (Domain: robot / Range: actuator)
- (OP) hasContext (transitive)
- (OP) hasEnvironmentCondition
- (OP) hasIdentity
- (OP) hasInteraction
- (OP) hasInteractionWorkflow
- (OP) hasRequirement (transitive)
- (OP) hasSensor (Domain: robot / Range: sensor)
- (OP) isActivityMissionOf (inverse of hasActivityMis- sion)
- (OP) isEnvironmentConditionOf (inverse of hasEnviron- mentCondition)

[5] This model is available to be incorporated or extended by other represen- tations at http://www.contextawarerobotics.org/cahri/kr/im-cahri.owl.

- (OP) isInteractionWorkflowOf (inverse of hasInteraction- Workflow)
- (DP) policyGraph (string).

V. CONCLUSIONS

In this paper we addressed the standardization of knowledge representation in autonomous robotic systems. We initially introduced the concept of ontologies and some examples of how this knowledge representation approach is being used in robotics. Consequently, we referred the standardization effort that contributed to the creation of the IEEE 1872-2015 - Standard Ontologies for Robotics and Automation. Addition- ally, this paper presented the results of current undergoing work in terms of extending this standard to its version IEEE 1872.2, which is expected to be submitted for approval in 2020, and will introduce an extension with new concepts that were not present in 2015. Hence, in this paper we presented an adaptation of the standard focusing on the example of developing ICT and robotics to provide services specifically designed for the elderly in order to enhance their everyday life and be provided with high-quality healthcare services. The results presented in the paper will contribute for the use case focusing in the Active Assisted Living application domain that is currently under development by some members of the IEEE AuR working group. In the future, we expect to integrate the proposed knowledge representation in robotic platforms that were developed to realize such use cases (e.g. GrowMeUp) and promote such standardization efforts in collaboration with relevant European research and innovation networks (e.g. LIFEBOTS Exchange, Digital Innovation Hubs for Robotics).

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Verification and Validation Solutions for Reliable Assistive Robots

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***Abstract* — The last decade has seen a growing number of research initiatives aimed at realizing intelligent robotic solutions for healthcare and/or social assistance also leveraging Internet of Things (IoT) features. Recent advancements in Artificial Intelligence (AI) and Robotics are fostering the diffusion of intelligent robotic agents capable of supporting both older adults and caregivers in a variety of common life situations. Decisional autonomy is considered one of the key cognitive functions for developing suitable system abilities in assistive robotics applications. This entails robotics platforms to be endowed with a wide set of automated reasoning capabilities to be implemented by means of suitable technologies such as, e.g., automated planning and scheduling (P&S). In this abstract, we argue that the integration of Verification and Validation (V&V) and P&S techniques represent an important contribution as it is of great importance to formally demonstrate the correctness of generated solutions and, as a consequence, significantly increase the trust of end users in such technology.**

Assistive Robotics

Ageing is one of the most relevant factors for frailty, dependency and level of received care [1]. The objective of fostering a good quality of life in elderly people basically means to cope with age-related health and cognitive impairments and the consequent decrease of independence. In this context, the development of new and innovative technologies to preserve the autonomy of elderly people in their own domestic environment is becoming important [2]. The last decade has seen a growing number of research initiatives and projects aimed at realizing intelligent robotic solutions for healthcare and/or social assistance also leveraging Internet of Things (IoT) features. For instance, the work made in RoboCare research project [3] represents a first important result in this field, whereas, projects like Mario [4], Robot-Era [5], or GIRAFF PLUS [6] are examples of more recent research initiatives that have shown progresses in realistic scenarios with real users.

Recent advancements in Artificial Intelligence (AI) and Robotics are fostering the diffusion of intelligent robotic agents capable of supporting both older adults and caregivers in a variety of common life situations. Such robotic agents must be capable of monitoring and internally representing information coming from the environment, interacting with humans in a flexible and human-compliant way, autonomously performing tasks inside the environment and also personalizing interactions and services according to the specific needs of an assisted person. The ability of dealing with different and heterogeneous sources and types of information constitutes a key feature to enable intelligent robotic assistants to understand health-related states and needs of older persons as well as the states of the environment it acts in. Also, the need of supporting daily and personalized assistance entails the exploitation of IoT devices to gather information about the living environment of the assisted person as well as his/her physiological parameters in order to figure out which assistive task or set of tasks is more suited for the detected situation. It is necessary to endow socially assistive robots with advanced cognitive capabilities to provide well suited and effective impact in healthcare assistance and achieve the challenging objective of prolonging elderly independence as well as increasing their quality of life. There are several research issues and open problems that must be properly addressed to achieve such challenging objectives. In our view, a number of advanced cognitive capabilities that range from knowledge representation and learning to decision making and acting need to be integrated [7]. Many AI techniques and technologies can give a precious contribution and play an important role in this context if properly integrated in a uniform control approach.

DECISIONAL AUTONOMY

Among others, decisional autonomy is considered one of the key cognitive functions for developing suitable system abilities in assistive robotics applications. This entails robotics platforms to be endowed with a wide set of automated reasoning capabilities to be implemented by means of suitable technologies. Among these, automated planning and scheduling (P&S) technology plays a crucial role [8]. In general, automated P&S systems are finding increased application in real-world mission critical systems that operate under high levels of unpredictability. Given a description of a desired goal, and a model of possible actions and their causal/temporal constraints, the planning problem consists of finding a plan, which is a sequence of actions, the execution of which is calculated to lead to the goal state under ”normal” circumstances. Such technology can be used to generate plans to control a robot, driven by goals issued by humans. Such technology is occasionally referred to as model-based autonomy and a P&S system takes as input a domain model and a goal, and produces a plan of actions to be executed, which will achieve the goal. A P&S system typically also offers plan execution and monitoring engines.

TOWARDS RELIABLE ASSISTIVE ROBOTS

To foster effective use of Automated P&S systems in (near future) robotics applications such as, for instance, assistive robots, it is of great importance to formally demonstrate the correctness of generated solutions and, as a consequence, significantly increase the trust of end users in such technology. In fact, automated P&S systems often bring solutions which are neither “obvious” nor immediately acceptable for them. This is mainly because these tools directly reason on causal, temporal and resource constraints; moreover, they employ resolution processes designed to optimize the solution with respect to non trivial evaluation functions. On the other hand, due to the non-deterministic nature of planning problems, it is a challenge to construct (and guarantee) correct and reliable P&S systems. That is, it is not straightforward to guarantee the correctness/reliability of P&S systems.

For this reason, we argue here that the integration of automated Verification and Validation (V&V) techniques represent an important contribution, adding value to these kinds of applications provided they can be gracefully integrated with P&S technology (e.g., see [9]). In fact, a failure on behalf of an automated decision support system or the generation of not fully safe robotic behaviors may have a dramatic impact in terms of loss of effectiveness, money, and even human life. In particular, an assistive robot following unsafe behaviors may put at risk or even harm human users. It is worth reminding that validation allows to check whether models, knowledge bases, and control knowledge accurately represent the knowledge as well as the objectives of the human experts (i.e., validation has to do with building the right system), while verification tells us whether the system (and its components) meets the specified requirements (i.e., building the system right). In robotics, V&V solutions have been developed and deployed at different levels. Just to mentions a few examples: the LAAS Architecture [10] has been redesigned leveraging the BIP engine in order to implement a correct-by-construction a functional control level [11]; Model checking techniques [12] have been exploited to verify whether a flexible plan generated by a P&S system is dynamically controllable [13] and to generate a dynamic execution strategy by solving a reachability game for Timed Game Automata (TGA) [14].

Our main point is that an important potential impact in assistive robotics can be done leveraging a recent research initiative aimed at developing a task planning and execution framework (PLATINUM) [15] and its integration with a Knowledge Engineering ENvironment (KEEN). KEEN [16] is a knowledge engineering environment with V&V features based on Timed Game Automata model checking. PLATINUM is a timeline-based planning systems capable of supporting flexible temporal planning and execution with uncertainty. Also the development of suitable tools to integrate such solutions with robotics technology (ROS) it is a relevant aspect to be considered [17]. It seems to us of paramount importance enriching an assistive robot control architecture with decisional autonomy and, at the same time, the ability to formally verify and, then, guarantee correct and proper behaviors with respect to a comprehensive set of requirements elicited after standard definitions (e.g., ISO 13482:2014) and/or user preferences (e.g., [18], [19]).

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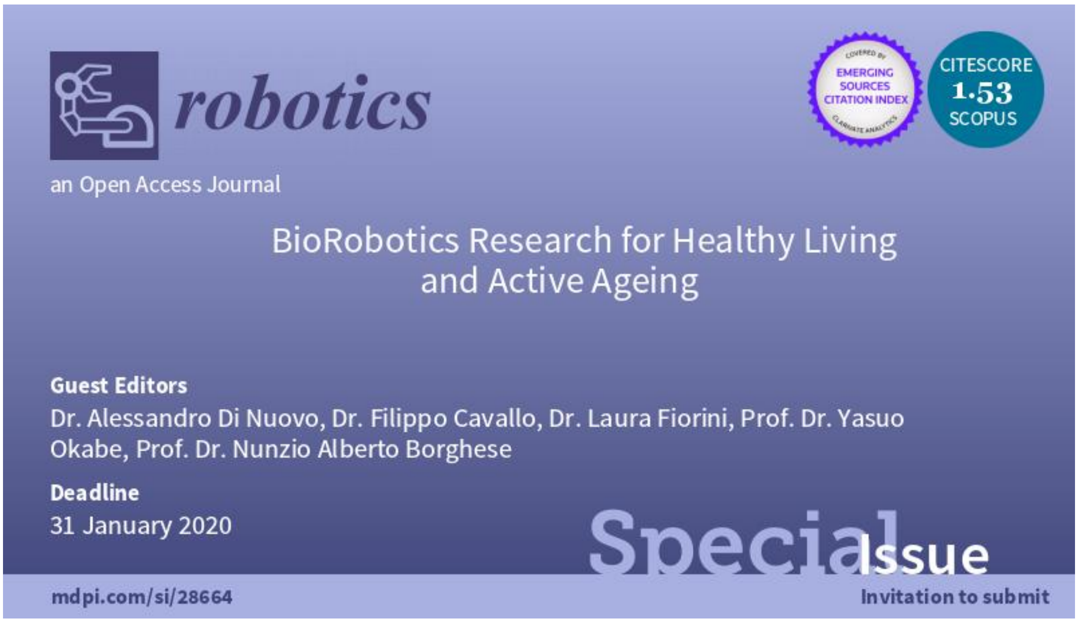
Special Issue

This workshop is linked to a Special Issue of the MDPI Robotics journal, titled **BioRobotics Research for Healthy Living and Active Ageing**. Authors of best contributions accepted at the workshop will be invited to submit an extended version to the special issue.



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