Assessing Usability of a Robotic-Based AAL System: A Pilot Study with Dementia Patients

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***Abstract*—Ambient Assisted Living is playing a crucial role in supporting dementia patients to live in their preferred environment, so limiting the involvement of careers and/or relatives. In order for such systems to become a reality, patients need to feel comfortable when interacting with them, and so an agent-based modular approach is adopted to make it possible to personalize the provision of digital services for each specific patient's needs. Here, we experiment with a robotic-based ambient assisted environment to analyze the perceived usability when real patients interact with it in a controlled research laboratory where the system is deployed, by taking into account both their personality traits and cognitive status. The perceived usability is evaluated through a survey with a set of patients filling a questionnaire specifically designed for the experimentation that is based on the Unified Theory of Acceptance and Use Technology (UTAUT). The preliminary obtained results show that the perceived usability of the system is related to some traits of patients' personality, while their cognitive status impacts the provided assistive services.**

***Index Terms*—Assistive robotics, workflow of services, personalization, QoS adaptation**

I. Introduction

Ambient Assisted Living systems equipped with social robots are reaching a great potential due to the advances in the Information and Communication Technologies, so making it possible their adoption for supporting home care of patients with mild neurological disorders, or at initial stages of the Alzheimer's disease. Such systems may help to provide cognitive and physical stimulation to patients, crucial to limiting their cognitive reserve, to remind tasks that have to be carried out during the day, and to monitor their activities, so alleviating the already heavy burden on careers and/or relatives. Nevertheless, the interaction of a very vulnerable category of users, such as Alzheimer's patients, with these systems may strongly impact their effective use [1]. In fact, interactive devices, as robotic systems, whose behavior is not compliant with the needs and the characteristics of each patient, may cause discomfort so preventing her/him from using it.

In this work, we report the approach adopted in the *User-Centred Profiling and Adaptation for Socially Assistive Robotics* (UPA4SAR) project, whose objective is to develop an affordable, easy to deploy, and well accepted AAL system based on a social robot to deliver assistive services for home patients affected by Alzheimer's disease. The aim of the project is to improve the level of acceptability of social robotics through the possibility of adapting robots' behavior to the patient. The innovative character of the project concerns the realization of new models of assistance and provision of services in the health sector, which aim at a "patient-centric" vision. To this end, the project proposes the use of a robotic system that allows the automatic adaptation of the robot's behavior to the personality profile, preferences, and cognitive status of the user, in order to provide an adaptive interaction. The main task of the robot is the monitoring of the patient's quality of life (through the recognition of the activities he/she performs) and cognitive support. In this work, we present the results of a first experimentation performed with the complete prototype of the system.

II. A Robotic-based AAL System

In order to support home-care assistance for patients affected by neurological disorders, a robotic-based ambient assisted environment has been developed within the UPA4SAR project whose goal is to provide an affordable and well-accepted robotic assistive system, able to generate and execute assistive plans and actions that are personalized for each specific patient, and that can be adapted during execution to changing conditions in both the home environment, and the patient's conditions [2].

At this purpose, a service-oriented approach (SOA) is adopted to decouple a required functionality from its concrete implementation that is characterized both by the device that provides it, and by Quality of Service (QoS) parameters referring to the way it is delivered [3]. This service-based approach allows both the execution of services on computing resources outside the robot, and the integration of services that can be provided by the robot with services provided by other devices in the house, or even by services provided by a caregiver, thanks to the possibility of representing an assistive action as a service according to an interface and standard communication protocols.

The system architecture is composed of different layers:

- the *Data Computational Model*, i.e. the knowledge base containing static and dynamic information both on the patient, and on the home environment; dynamic information includes the current user activity, his/her physical and emotional state, his/her current location, that are collected through the available sensors (including the robot) and updated from time to time; static information contains: the patient *Daily Routine*, i.e. the set of daily activities that he/she has to carry out throughout the day at given times, the *Personality Profile*, reporting measures of five personality traits, i.e. Neuroticism, Extraversion, Openness, Agreeableness, and Conscientiousness, assessed through the NEO Personality Inventory test [4]; the *Cognitive Profile*, characterizing cognitive and functional performance of Alzheimer's patients and assessed through the ACE-R (Addenbrooke's Cognitive Examination) test [5];
- the *Assistive Workflow Management*, i.e., the middleware responsible for the execution of personalized assistive plans represented as a workflow of services [6];
- the *Daily Assistive Actions*, i.e. the set of concrete service implementations provided by the technological devices, that is periodically updated to take into account their dynamic availability;
- the *Smart Environment*, i.e. the set of technological devices deployed in the home environment that are: a Sanbot Elf, that is a low-cost mobile humanoid robot endowed with a tablet and an RGB-D camera (see Figure 3), iBeacons used for the indoor positioning system, able to transmit a signal using Bluetooth Low Energy (BLE) technology, a Polar M-600 smartwatch, and a Samsung Smartphone.

All the considered devices are android-based, hence android applications are developed to communicate with their sensors and actuators. The workflow management subsystem is running on a PC where also user data are stored. The communication among all components of the system, the services and the IoT devices, is based on Web Socket protocol using Socket.IO, a JavaScript library for real-time web applications that enables real-time, bi-directional and event-based communication between web clients and servers, and JSon messages. A server, running on the PC, manages the communication between the workflow manager and the concrete services.

III. Agent-based Abstract Services for Home Assistance

Starting from the patient's daily routine (as reported in Table I, the Assistive Workflow Management subsystem is responsible for the generation of high level plans listing the necessary daily assistive tasks required for assisting patients. It is an agent-based middleware that, once assistive tasks are declared in an XML format, it generates plans to perform them, composed of the required functionalities, and their execution order requirements. According to the adopted service-oriented approach, such assistive task is represented as a workflow of abstract services, i.e. abstract functionality necessary to perform the task. An example of daily routine and the corresponding high level plan, known as an *Abstract Assistive Plan*, represented in XML, are here reported.

TABLE I
DAILY ROUTINE

Time Range	Daily Activity
07:00 - 07:30	Wake-up
07:30 - 08:00	Breakfast
09:30 - 11:00	Cognitive Entertainment
11:30	Take medicine
12:30 - 13:30	Lunch
14:00 - 16:00	Resting
16:00 - 18:00	Go out
18:30 - 19:30	Physical Entertainment
20:00 - 21:00	Dinner


```
<?xml version="1.0" encoding="UTF-8"?>
<DailyRoutine>
    <Activity>
        <NameActivity>WakeUp</NameActivity>
        <AbsWorkflow>WakeUpMonitoring</AbsWorkflow>
        <StartDate>2019-04-24</StartDate>
        <StartHour>7:00:</StartHour>
        <EndtHour>7:30:</EndtHour>
    </Activity>
    <Activity>
        <NameActivity>Breakfast</NameActivity>
        <AbsWorkflow>BreakfastMonitoring</AbsWorkflow>
        <StartDate>2019-04-24</StartDate>
        <StartHour>7:30:</StartHour>
        <EndtHour>8:00:</EndtHour>
    </Activity>
    <Activity>
        <NameActivity>CognEntertainment</NameActivity>
        <AbsWorkflow>SuggestCognStimul</AbsWorkflow>
        <StartDate>2019-04-24</StartDate>
        <StartHour>09:30</StartHour>
        <EndtHour>11:00</EndtHour>
    </Activity>
    <Activity>
        <NameActivity>TakeMedicine</NameActivity>
        <AbsWorkflow>MedicineRemind</AbsWorkflow>
        <StartDate>2019-04-24</StartDate>
        <StartHour>11:30</StartHour>
        <EndtHour>11:30</EndtHour>
    </Activity>
     .....
     .....
</DailyRoutine>
```


Each assistive task is referred to as an `AbsWorkflow`, a graph of abstract services, i.e. high level functionalities each one managed by an *AbstractServiceAgent* responsible

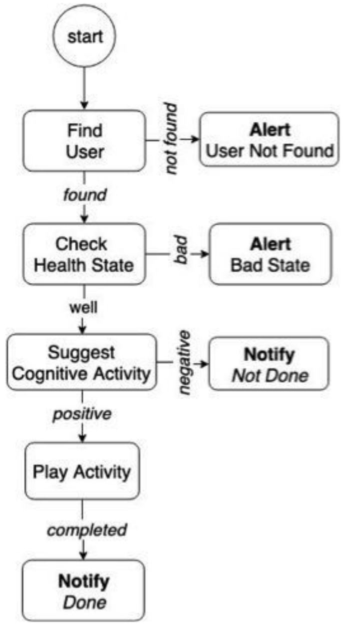

Fig. 1. The abstract workflow for suggesting a stimulation activity

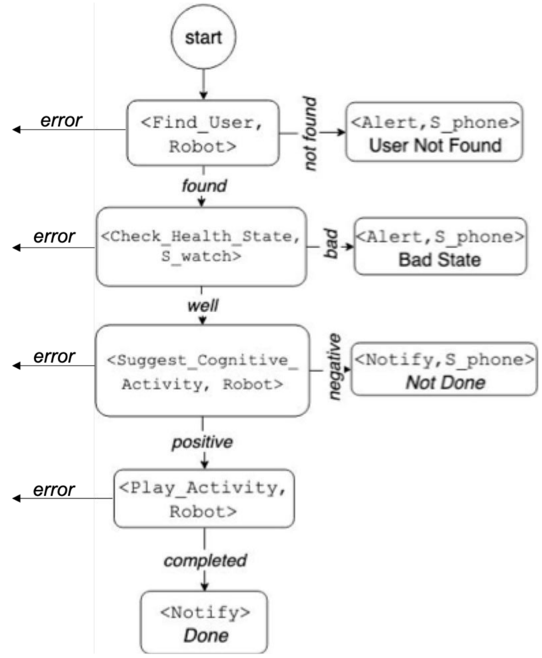

Fig. 2. The concrete workflow for suggesting a stimulation activity

for the lookup of the concrete services available to provide the required functionality, and to contact the corresponding providers represented as a *ConcreteServiceAgent*.

In Figure 1 the `SuggestCognitiveStimulation` abstract workflow is reported, with the abstract services required to perform it. For each abstract service, the corresponding AbstractServiceAgent issues a request to the available ConcreteServiceAgents, and it selects the first ConcreteServiceAgent that replies or more complex mechanisms for ordering the replies can be implemented [7]. Once selected, the ConcreteServiceAgent is responsible for instantiating the QoS parameters of the concrete service it provides, according to the cognitive status and the personality profile of the specific patient. Currently the only QoS parameter considered is the repetition frequency at which each service is executed.

This selection process is repeated for all abstract services in the workflow, until all of them are instantiated with a concrete implementation resulting in a concrete workflow, as the one reported in Figure 2, ready to be executed by the selected providers. The type of entertainment activities are randomly selected among the ones preferred by the patient and reported in the user profile.

During the execution of the concrete workflow, as shown in Figure 3, concrete services may fail due to either a timeout for getting the service output, or for an unavailability of the device delivering the service. In such cases, the corresponding AbstractServiceAgent receives the error message and it selects the second ConcreteServiceAgent that replied to the initial call, and so on. If all available devices fail, then the workflow execution ends with a failure and a notification to a human career is signaled.

A. *Selection of Concrete Services*

ConcreteServicesAgents, within the android applications, are android services (i.e., threads working in background that can be invoked via socket messages) and activities (for GUI). A web interface used to activate concrete service individually is shown in Figure 4.

Currently, the types of available services are: 1) Monitoring Services that include activity recognition via a wearable device or via camera using pose/skeleton recognition, emotion and disengagement recognition, 2) Navigation Services for searching and approaching the user, 3) Interaction Services for speech recognition and speech synthesis using multimodal interaction with the user.

1) Monitoring Services: Monitoring services are developed to monitor and recognize the current state of the user and the performed Activities of Daily Living (ADLs) and instrumental Activities of Daily Living (IADL).

In the current version of the system the state of the user is evaluated through *HR Detection* service and *Emotion Recognition* service. The first aims at getting the current heart-rate of the patient from the smartwatch and the average value of 15 second of lectures is provided as a result. In the second, the robot takes a video of the person that is analyze by the Affectiva SDK; this service returns the emotion (joy, surprise, contempt, disgust, sadness, anger) of the person with the highest mean on the whole video.

ADL and IADL can be monitored by using either *Pose Detection*, *Activity Classification*, or *Dialogue Check*. The Pose Detection service aims at evaluating the current pose of the user from wearable data. The robot communicates with the smartwatch via Bluetooth to take 512 data samples from the smartwatch accelerometer and use a deep neural network

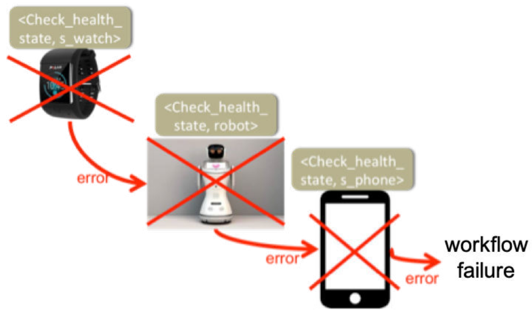

Fig. 3. Selection of different devices for the same abstract service

for the classification process [8]; the recognized activities are: standing up, getting up, walking, running, going up, jumping, going down, lying down, sitting down. The Activity Classification service implements an Activity Recognition algorithm by analyzing a video sampled from the robot camera to detect the skeleton pose for each video frame [9]. The activity recognition works again with a deep neural network on a window of 140 frames of human skeleton data with 30 fps. The activity recognized are watching tv, relaxing on couch, ironing, making coffee, working at PC, and talking on the phone. Finally, the Dialogue Check service allows to use the robot GUI to directly ask a question to the user regarding his/her activity. Two buttons (for positive and negative answers) are showed on the robot tablet (e.g. a question can ask if the user has taken the medicines).

Two additional services, *In Room Detection* and *In Room Detection with Robot*, are developed to infer additional information on the user state and activity. In details,with the In Room Detection service the robot contacts the smartwatch via Bluetooth to know the position of the person in the house; the smartwatch communicates with the beacons placed in each room of the house to calculate the distances between the user (that wears the smartwatch) and the beacon; this service returns the label of the room with the beacon at minor distance from the smartwatch, so locating the person into the house. The same behavior can be exploited by the robot itself, when it is in the presence of the user.

2) Navigation Services: These services are developed in order to make the robot able to navigate within the environment and to locate the user [10]. *Look user* is a simple service that moves only the camera, that is located in the robot head, to scan if there is a user nearby the robot. Images from the camera are processed by the use of the PoseNet service to identify a possible user. On the contrary, the service *Find User* is used by the robot to randomly navigate within the environment, avoiding obstacles, and searching for a user. Once the user has been detected, the *Approach* service can be requested to make the robot move to the correct interacting/monitoring position. Finally, the *Stop Robot* service is used to start the search for the charging station in order for the robot to charge its battery.

3) Interaction Services: Interaction modalities of the robot (voice interaction and GUI) can be used to suggest and show personalized entertainment activities to the user. In details,

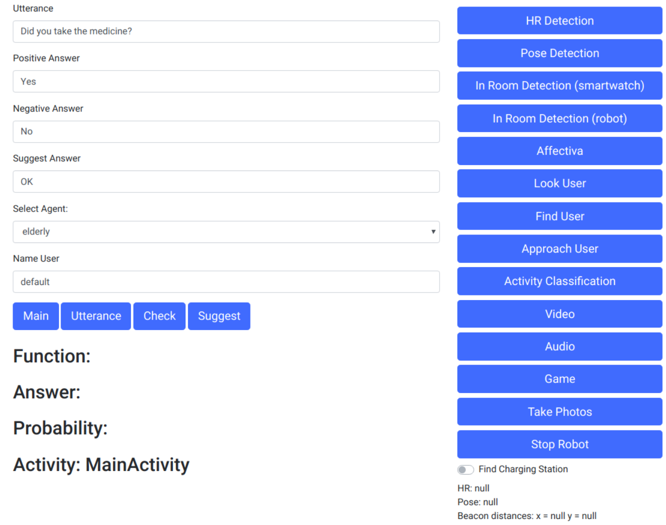

Fig. 4. Server interface to control individual services

the *Dialogue Suggest* service is used to suggest the activities, while the services *Video Entertainment*, *Audio Entertainment*, and *Game Entertainment* are invoked to show respectively, video, audio or games to the user.

IV. The Pilot Study

A prototype implementation of the robotic-based AAL system has been developed and tested in a controlled environment with real patients with different degrees of the Alzheimer's disease, recruited by the team of neurologists of the project[1].

The purpose of this preliminary experimentation was to evaluate a set of ratings to assess the general acceptance degree of the system according to the different cognitive and personality characteristics of the selected patients, by varying the repetition frequency of the interaction services suggesting various entertainment activities, in a user-transparent manner. To determine the strength of predictors for elderly participants' intention to accept and use the system, we adopted a modified version of the Unified Theory of Acceptance and Use of Technology (UTAUT) questionnaire [11] specifically designed by the team of psychologists of the project. This represents an instrument to measure the variety of perceptions of information technology innovations.

The rationale of the experimentation is to collect information on possible relationships between the modalities in which services are executed, and the cognitive and personality traits of patients. Such information will be used for a customization of the assistive tasks delivered by the system, so to improve its acceptance level, by selecting behaviors that result less disturbing for each patient because more compliant with his/her profile.

The patients were left alone in an area of the controlled environment resembling a house room, where they could perform different entertainment activities (read a book or a

[1]This experimental study has been approved by the ethical committee of the University Federico II with protocol number 167/18.

Fig. 5. One of the selected patients interacting with the system (left). The robot (right)

magazine, watching tv, listen to music, playing at a PC, take a refreshment). From time to time, a monitoring workflow was executed to check if the user was doing some activity. In case he/she was not performing any activity, an entertainment workflow was executed by varying the frequency when the entertainment was suggested. Each user interacted with the system for approximately three hours.

A. Patients' Traits Classification

The present study included four subjects (two men and two women) between 71 and 75 years old. All subjects performed a cognitive screening test (ACE-R) [5], and a personality questionnaire (NEO PI -3) [4]. The first subject (man; age = 74; years of education = 8) showed a cognitive decline with significant difficulties of memory and fluency. The personality profile showed low levels of neuroticism and normal levels of openness, without depressive symptoms. The second subject (woman; age = 75; years of education = 5) showed a cognitive decline with significant difficulties of memory, attention, fluency and language. The personality profile showed higher levels of neuroticism and low levels of openness, with depressive symptoms. The third subject (woman; age = 71; years of education = 8) did not show a cognitive decline, but light memory difficulties. The personality profile showed normal levels of neuroticism and high levels of openness, without depressive symptoms. The last subject (man; age = 75; years of education = 18) did not show a cognitive decline, but only slight difficulties in memory tasks. The personality profile showed lower levels of neuroticism and normal levels of openness, without depressive symptoms.

B. A UTAUT-based Usability Test

We adopted the version of the UTAUT questionnaire proposed by [12] because it was already adapted and validated in the similar context of assistive robotics applied to elderly users. This UTAUT questionnaire consists of 41 items and explores 12 constructs: Anxiety (ANX), Attitude (ATT), Facilitating conditions (FC), Intention to use (ITU), Perceived adaptability (PAD), Perceived enjoyment (PENJ), Perceived ease of use (PEOU), Perceived sociability (PS), Perceived usefulness (PU), Social influence (SI), Social Presence (SP) and Trust. Subjects are required to reply to each item on a Likert type scale (range: 1-5).

TABLE II
UTAUT RESULTS

Code	Construct	Max	Min	Avg	Std
ANX	Anxiety	5	3	3.9	0.8
ATT	Attitude	4	2	3.2	0.8
FC	Facilitating conditions	4	2	2.8	0.9
ITU	Intention to use	4	3	3.3	0.5
PAD	Perceived adaptability	4.3	3	3.7	0.6
PENJ	Perceived enjoyment	4.6	2.8	3.4	0.8
PEOU	Perceived ease of use	3.6	2.4	3.1	0.5
PS	Perceived sociability	5	2.5	3.8	1.0
PU	Perceived usefulness	3.7	3	3.3	0.3
SI	Social influence	4	1	2.5	1.3
SP	Social presence	4.4	1.6	3.1	1.1
TR	Trust	4	2	3.1	0.9

The questionnaire was translated from English to Italian by two psychologists and an engineer, that were proficient in English and Italian and familiar with HRI. The translation was examined at a consensus meeting, back-translated, and approved at a second consensus meeting. A comprehension test was carried out in a subgroup of 15 individuals aged 18 years. This consisted of a face-to-face interview during which the interviewer inquired whether the subject had any difficulty in understanding the questions and the pre-coded answers. A comprehension rate was obtained as the percentage of questions and pre-coded answers of all items correctly understood by subjects. In the test, more than 90% of subjects found the questions easy to understand and had no difficulty in interpreting the answer modes. The final Italian version of the questionnaire is available from the authors upon request.

Results of the UTAUT evaluation is shown in Table II. We consider a positive perception of a participant when the construct score is greater than 3, while a negative perception is when average score is lower than 3 (in a scale from 1 to 5). Facilitating Conditions and Social Influence are the only two constructs obtaining a score lower than 3. However, these results are compatible with our experimental setting that was tested by the patients left alone, without involving caregivers, in a simulated home environment in the research laboratory, and so not a real domestic environment. Indeed, Facilitating Conditions refers to factors in the environment that facilitate use of the system, while Social Influence refers to the perception that people who are important for the subject think he/she should or should not use the system.

In addition, it was noticed that the patient with a low education level, depressive symptoms, and a high neuroticism was less incline to be engaged in the interaction with the robot, and so to accept its suggestions. On the contrary, patients with similar cognitive decline, but with a higher education level and lower neuroticism showed a better acceptance and a stronger engagement with the robotic system. These results are encouraging in showing that personality traits, more than cognitive decline, play a crucial role in the acceptance of the robotic system and so it has to be taken into consideration for personalization of patient-system interaction.

V. Conclusions

In this work, we presented a general overview of the proposed approach and the software services developed in the context of the UPA4SAR project. Moreover, we presented the results of a pilot study that we conducted in a research laboratory environment with 4 real end-users recruited for the project.

The experimentation highlighted a general good acceptance rate of the system, even if, in the case of the patient with an high neuroticism, the interaction with the robot was limited. Moreover, from the users' free comments, we observed a immediate attachment to the robot. These results are encouraging for the next experimental stage that will be conducted directly in the patients' homes. In this stage, 40 patients will be recruited (20 with a mild level of Alzheimer, 10 with a moderate level and 10 with a subjective memory disorder), and the robot will stay in their home for 14 days each. This longer period, will allow us to collect more reliable data regarding the acceptance rate of the robotic-based AAL system to better tune the adaptation of the robot's behavior with respect to each single patient. Indeed, the robot is also able to adapt its own social interaction parameters, such as the proxemics, the speed of movements, and the interaction modalities, so future work are planned to consider also these QoS parameters to be tuned to validate the reliability of the proposed design choices. It is expected that the adaptation of these parameters to the specific user's profile will allow to overcome the novelty effect caused by the robot presence and to evaluate its long-term effectiveness.

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References

[1] E. Broadbent, R. Stafford, and B. MacDonald, "Acceptance of healthcare robots for the older population: Review and future directions," *International Journal of Social Robotics*, vol. 1, no. 4, p. 319, Oct 2009.

[2] S. Rossi, G. Ercolano, L. Raggioli, M. Valentino, and C. Di Napoli, "A framework for personalized and adaptive socially assistive robotics," in *Proceedings of the 19th Workshop "From Objects to Agents" - Vol. 2215*. CEUR, 2018, pp. 90–95.

[3] C. Di Napoli, "Software agents to enable service composition through negotiation," *Studies in Computational Intelligence*, vol. 170, pp. 275–296, 2009.

[4] R. R. McCrae, J. Paul T. Costa, and T. A. Martin, "The neo-pi-3: A more readable revised neo personality inventory," *Journal of Personality Assessment*, vol. 84, no. 3, pp. 261–270, 2005.

[5] E. Mioshi, K. Dawson, J. Mitchell, R. Arnold, and J. R. Hodges, "The Addenbrooke's cognitive examination revised (ace-r): a brief cognitive test battery for dementia screening," *International Journal of Geriatric Psychiatry*, vol. 21, no. 11, pp. 1078–1085, 2006.

[6] C. Di Napoli, M. Valentino, L. Sabatucci, and M. Cossentino, "Adaptive workflows of home-care services," in *Proceedings of the 27th IEEE International Conference on Enabling Technologies: Infrastructure for Collaborative Enterprises (in press)*. IEEE, 2018.

[7] C. Di Napoli, P. Pisa, and S. Rossi, "Towards a dynamic negotiation mechanism for qos-aware service markets," in *Trends in Practical Applications of Agents and Multiagent Systems*, ser. Advances in Intelligent Systems and Computing. Springer International Publishing, 2013, vol. 221, pp. 9–16.

[8] S. Rossi, L. Bove, S. Di Martino, and G. Ercolano, "A two-step framework for novelty detection in activities of daily living," in *Social Robotics*. Cham: Springer International Publishing, 2018, pp. 329–339.

[9] G. Ercolano, D. Riccio, and S. Rossi, "Two deep approaches for adl recognition: A multi-scale lstm and a cnn-lstm with a 3d matrix skeleton representation," in *26th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, Aug 2017, pp. 877–882.

[10] G. Ercolano, L. Raggioli, E. Leone, M. Ruocco, E. Savino, and S. Rossi, "Seeking and approaching users in domestic environments: Testing a reactive approach on two commercial robots," in *27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, Aug 2018, pp. 808–813.

[11] V. Venkatesh, M. G. Morris, G. B. Davis, and F. D. Davis, "User acceptance of information technology: Toward a unified view." *MIS Quarterly*, vol. 27, no. 3, pp. 425–478, 2003.

[12] M. Heerink, B. Kröse, V. Evers, and B. Wielinga, "Assessing acceptance of assistive social agent technology by older adults: the Almere model," *International Journal of Social Robotics*, vol. 2, no. 4, pp. 361–375, Dec 2010.