

What is my Robot Doing? Remote Supervision to Support Robots for Older Adults Independent Living: a Field Study

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Abstract—In an ageing society, the at-home use of Socially Assistive Robots (SARs) could provide remote monitoring of their users' well-being, together with physical and psychological support. However, private home environments are particularly challenging for SARs, due to their unstructured and dynamic nature which often contributes to robots' failures. For this reason, even though several prototypes of SARs for elderly care have been developed, their commercialization and widespread at-home use are yet to be effective. In this paper, we analyze the impact of introducing a novel web-based Monitoring and Logging System (MLS) on the SARs reliability and user acceptance. This monitoring framework, specifically designed for remote supervision and control of SAR-based systems in older adults' apartments, also allows exchanging feedback between caregivers, technicians, and older adults, to better explain the SAR-based systems' behaviours. The MLS was developed, tested, and evaluated within the pilot study of the H2020 project MoveCare, where 13 autonomous SARs were deployed in the house of older adults living alone and remotely monitored for over 180 weeks. The results from this field trial suggest that the use of the MLS during the pilot increased the acceptance of the SAR-based system in the event of failures and anomalies.

I. INTRODUCTION

An ageing population brings many challenges to societies' healthcare and social systems. Assistive technologies are often investigated to propose innovative and cost-effective solutions to improve the quality of elderly care [1].

One of the goals of the development of at-home assistive solutions is to prolong and sustain the independent living of older adults by remotely monitoring their health and well-being. The intention is to provide support within their comfortable home environment, delaying their admittance into the more controlled (but more expensive and often overpopulated) setting of care homes.

In this context, Socially Assistive Robots (SARs) are a new and useful technology for remote monitoring, stimulation, and assistance [2]. Moreover, the presence of an assistive robot at home can be used to facilitate the communication between older adults and their caregivers [3].

Although SARs for elderly care have been developed [4], [5], the gap yet to be filled to move from those prototypes to their widespread diffusion is still significant. Among other



Fig. 1: A Giraff-X robot inside the house of an older adult.

factors, this is due to the fact that the functionalities they offer to their end-users are limited (wrt the users' expectations), and that they lack *reliability* (wrt their robustness).

Home environments are particularly challenging for SARs, due to their unstructured and dynamic nature [6]. Hard passages, narrow doorways, cumbersome furniture, obstacles on the floor, and the presence of a person on their path are examples of the many contingencies that can affect robots' navigation. Similarly, features such as mirrors, french windows, curtains, and moving objects (e.g., chairs around a table) may affect robots' localization. All of these issues may ultimately cause a *failure* in robots' navigation and localization functionalities, undermining the reliability of the whole system the robot is operating into. Long and costly recovery procedures are often needed to resolve such failures and typically involve external interventions from trained personnel.

SARs can experience *environmental*-driven failures, due to the fact that the robot cannot perform its tasks because of a physical limitation (i.e., an obstacle blocking its path, its vision not working at night), or *system*-driven failures, due to both software or hardware failures (e.g., a motor, or the batteries) of the robot or of one external component of the Ambient Assisted Living (AAL) environment they are often integrated with. The chances of a failure eventually happening are amplified by the fact that SARs need to work in these unsupervised and uncontrolled settings for long periods of time and with persistence. Modern robots' skills are often not enough to fulfill the stability and reliability requirements imposed by a long-term deployment into a complex and unpredictable environment, such as their users' houses. As a consequence, the safety concerns that arise in their potential users and the lack of trust towards the machine have a negative

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impact on SARs acceptance [7].

While we would like to have a system that could overcome such limitations autonomously, in practice, we are far from this scenario. At the current development stage of SARs, when they can still experience multiple failures, robots need a certain degree of external *control* and *remote supervision* to be fully operative [8]. Providing remote supervision of SARs could not only improve their safety and robustness but also mitigate issues arising from possible failures, ultimately increasing their acceptability: if the robot shows an anomalous behaviour, older adults could feel safer knowing that there is someone taking care of the problem. In such scenarios, older adults would also be able to ask the remote supervisor to *explain* the robot's behaviour later on. Note how even the intended robot behaviour can be perceived as anomalous by users if robot actions are not understood, thus requiring an explanation.

The aim of this paper is to present a web-based cloud-robotics Monitoring and Logging System (MLS) designed to provide external supervision over a SAR-based system. The developed MLS enables supervisors, technicians, and caregivers, to remotely detect and deal with anomalous robot behaviours, also enabling explainability for the users. The use of this system allowed to support the fragile autonomy of an autonomous mobile SAR in a long-term deployment (180 weeks) in the houses of 13 older adults during a pilot study for the H2020 MoveCare project.

The proposed MLS was used to: a) monitor the correct functioning of each deployed SAR-based system during the experimental campaign, b) check issues and failures (even before they become critical) c) check and assess anomalous and strange behaviours signaled by the user.

This, combined with the fact that the users were allowed to contact a technician to signal the strange behaviours of the system and to ask for an explanation, was used to create a feedback loop between caregivers, technicians, and older adults. This way, users could ask explanations on the behaviours of the system (increasing its *explainability*) and technicians/caregivers could both reassure the users and improve the system by adapting it to their needs, creating a continuous integration loop. Eventually, the use of the MLS during the pilot of MoveCare increased the acceptance of the SAR-based system in the event of failures and anomalies.

In the following sections, we provide an empirical evaluation of the utility of the developed MLS by presenting acceptance results from structured questionnaires and by reporting use cases of how remote monitoring was able to handle critical scenarios experienced during the pilot study.

II. RELATED WORK

The term SAR refers to a class of robots defined as being at the intersection of socially interactive robots, focusing on engaging and *stimulating* the users through social and nonphysical interactions, and assistive robots, whose aim is to overcome the patients' physical limitations by helping in their daily activities (such as getting out of bed, brushing teeth, walking, etc.) [2].

Systems based on SARs represent a promising technology aiming at providing assistance to older adults through social interactions, and their functionalities are often investigated with structured interviews and controlled pilot studies, as in [3], [9], [10]. In this context, SARs are often based on autonomous mobile platforms that, thanks to a high level of integration into AAL environments and cloud-based frameworks [8], are able to provide services such as the delivery of messages and reminders, teleconference with family members or caregivers, and guidance through physical or cognitive exercises [5]. However, in these works, the cloud-based infrastructure was not acting as a monitoring system and it was not used as a way to provide explainability to the end-users. It was more an instrument for the researchers to be present during the deployment at-home of the SAR-based system.

In recent years, several projects have been investigating the deployment and use of SARs within home environments [4], [5], [11]. While these works have successfully assessed the use of SARs in such environments for a short period of time, there is still a significant gap between the current abilities of SARs and those required for a robot to be able to reach long-term autonomy (LTA) [6] in uncontrolled environments. As a result, experiments involving SARs for older adults' independent living often offer in-presence supervision of the robot or investigate the possibility to create a mutual-care network where the robot and the user support each other [12].

Recent works like [13] or [14] have done a remarkable effort towards the long-term and widespread adoption of SARs by deploying them, for several weeks, in settings like an assisted living facility. Other relevant long-term applications of autonomous social robots are those of [15] and [16]. Differently from our settings, in both studies, the robot was deployed in less challenging and more controlled environments. In our context, we aim to provide an assistance robot to serve older adults in their own houses.

A similar system to the one we are proposing can be found in the work done for the CompanionAble and SERROGA projects [11], [17]. In their works, similarly to what we discuss in Section V, they presented results on the performance of a SAR-based system tested in private apartments. Another recent research effort presenting a service robot focused on fall detection and offering additional services such as reminders and entertainment suggestions is described in [5]. The main difference between these studies and ours lies in the fact that we provide results obtained in a significantly longer experimental campaign, where multiple robots were used at the same time for several months in the end-users' own houses. Moreover, the deployments described in the aforementioned works do not explicitly offer the possibility of remotely control the SAR-based systems, nor give the opportunity to caregivers and technicians to easily engage with them.

III. SYSTEM ARCHITECTURE

The MoveCare system is an AAL framework developed around Giraff-X, an autonomous mobile SAR, and composed

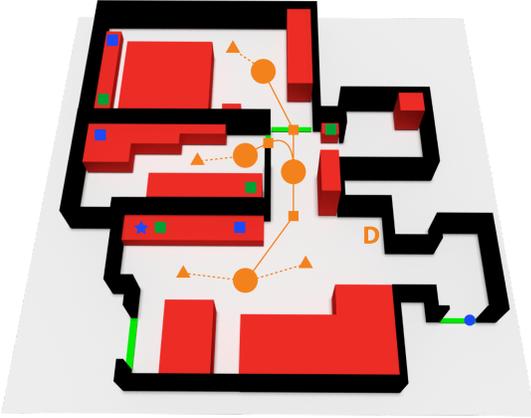


Fig. 2: An example of the setup in one of the pilot houses. The robot uses a *topological map* (in orange), represented as a graph where nodes represent rooms (circles), and edges represent a connection in the map. Each room could be associated with a set of *poses* (triangles), location of interests for the robot, where it could identify the user. Poses are the targets of robot navigation. When idle, the robot is at the docking station (D). The IoT network (blue) monitors the user with PIRS (squares) and a door sensor (circle). A concentrator (star) provides connectivity to the cloud. Smart microphones (green) listen to voice commands from the user.

of several components installed in the apartments of older adults living independently on their own [18]. Besides the robot, the other components are an IoT network, which is used to monitor the user and to provide information to the other components, a Community Based Activity Center [19], and a Virtual Caregiver (VC), a software component acting as platform orchestrator [20]. An example of how such components are installed is shown in Fig. 2.

All components interact together to carry out a set of *scenarios* designed to provide assistance, support, and physical and cognitive stimulation to older adults. Examples of such scenarios are described in [21], [22], and shown in these videos¹.

A. Giraff-X Socially Assistive Robot

Giraff-X, an enhanced and autonomous version of the Giraff teleoperated robot explicitly developed for AAL [23], [24], is the main actor of the system and is responsible for executing the scenarios. Fig. 1 shows one of the robots during the pilot.

The robot is designed to operate unsupervised for a continuous period of time in own apartments of older adults (see [25] for a detailed description of the sensors and instrumentation). As the main actuator of the system, it provides a set of functionalities in the form of *interventions*, or services, embodying the caregiver in the user’s house.

To do so, it:

- 1) receives the intervention to be executed via MQTT message;
- 2) undocks (if necessary);
- 3) safely navigates to the expected user location (updated by the system in real-time thanks to the IoT network);
- 4) locates the user or, if not found, performs a search in the whole house;
- 5) approaches the user, taking into consideration the proxemic distances [26];
- 6) interacts with the user to carry out the specified scenario;
- 7) provides feedback to the VC;
- 8) returns to the docking station (if there is not any other intervention planned in a short time interval [27]).

During the day, the robot is constantly active at its docking station, waiting for a task to be performed, received through an MQTT channel; on average, the robot performs 3-5 interventions each day. The main purpose of the robot is to perform this procedure autonomously, without any external help. In this context, robustness is crucial: a failure of the robot, requiring remote or in-presence intervention by a technician, would be undesirable and costly. Moreover, such an intervention may undermine the perceived utility of the robot and, consequently, its acceptability in the eyes of the users.

Giraff-X interventions can be requested by the system (when it needs to interact with the user), or can provide assistance services directly requested by the users (e.g., in case they need help). In addition, some interventions are directly triggered by the robot, as self-management, to maintain a proper autonomy level (e.g., triggering auto-docking if the battery level is critical).

1) **Robot Communication:** Giraff-X interacts with the other system components through JSON messages, sent through an MQTT channel to a shared cloud platform. This way, the robot receives the intervention to execute for a specific scenario and, upon completion, provides a report including information regarding the steps carried out for its completion and the outcome of the execution (success/failure). Besides this, the robot constantly updates the system with a message reporting its status: its pose in the map, its topological location, its battery status, its current and pending tasks, and a list of objects/people detected (using vision).

2) **Robot Failures Management:** Regarding robustness and fault tolerance during the challenging navigation within the home environment, we introduced a navigation assistant procedure, that detects and automatically inserts waypoints within the problematic areas of the apartment (i.e., doorways) to generate easier trajectories and assist the robot navigation [28]. However, if the robot is unable to complete its task autonomously, Giraff-X informs the VC about the possible cause of the problem, and automatically tries to reach its docking station. If the problem persists, and after three failed docking attempts, the robot asks (by voice) for help to the user. The user is instructed by Giraff-X to either assist it with the problem (e.g., by removing objects interfering with the robot navigation, like a chair), to manually move the robot

¹<http://www.movecare-project.eu/index.php/results/videos/>

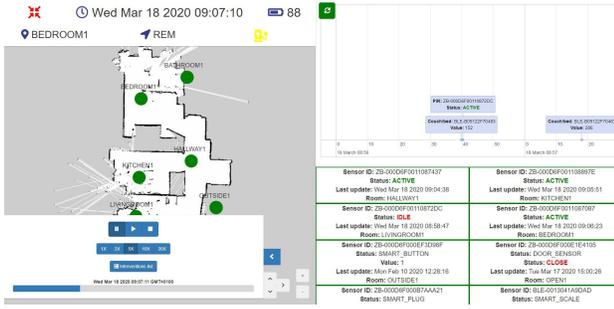


Fig. 5: The replay functionality is used to trace back all events that lead to a particular behaviour, to better understand it.

In addition, every 30 minutes, the MLS saves a snapshot of the current status of all the installed systems in its DB. This way, system administrators have the possibility to *replay* the history of events on an interactive timeline (as in Fig. 5). This feature provides key support upon system failures since it easily allows to retrace in chronological order the chain of events that led to the anomaly. Through its web interface, it is possible to control the status of the system in the chosen time interval, jump to the desired playback time, and select a playback speed for the selected timeline (from 1x, to 20x). The timeline also allows changing the resolution of the temporal axis to refine/coarse the level of historical detail. The proposed web architecture allows accessibility, and rich flexibility to the SAR-based system, which can be enriched by other types of sensors/data (provided that those are integrated inside the MQTT communication infrastructure).

V. FIELD EXPERIMENTATION

In this section, we present the results on the use of the MLS obtained during the pilot study for the MoveCare project. During the pilot, the entire system was installed inside the house of older adults aged 65 or more, not suffering from any cognitive impairment, and living independently on their own.

The field experimental campaign was run in two rounds, the first one (R1) from September to December 2019, the second one (R2) from January to April 2020. Participants were located in the city of Milan (Italy) and Badajoz (Spain).

Overall, 13 older adults (average age 77.8) participated in the pilot and received the system installed in their own house: 8 from R1 and 5 from R2. Three participants from R1 decided to carry on with the study also to R2 (extending their use of the system from 3 to 6 months). Each participant used the system in their apartment for at least 10 weeks during each pilot round. The robots were functional for a consecutive time of more than 180 weeks combined.

A. On-field Use Cases

As the pilot was executed in particularly challenging settings, we experienced several critical and unexpected behaviours from the SAR-based system. However, during the trial, users could contact a technician to ask for explanations

on the robot's behaviours or to signal a problem. The MLS was used to provide feedback to the users, who largely exploited this possibility especially in the early days of the pilot deployment, to explain the robot's behaviours (e.g., when the robot tried to return to its docking station after an intervention), improving the overall explainability and acceptability of the MoveCare system. At the same time, the MLS was used by the technicians and the caregivers to remotely and transparently assess the status of the systems installed in the users' houses.

We provide here a set of use cases, derived from situations that aroused during the pilot and that were successfully managed thanks to the use of the MLS. With these examples, we aim to discuss how having a remote monitoring and control system is particularly important for the widespread adoption of SARs.

Critical Night Failure At the beginning of R1, USER-1 experienced a failure in the IoT network: one of the microphones wrongly detected a "call for help" request at midnight. In response to this wrongly detected need, the robot tried to locate the user to confirm the request. The unsuccessful search lasted for approximately half an hour (as the robot was unable to reach the user who was in the bedroom with the door closed); eventually, the robot was unable to return to the docking station due to being stuck inside a room by a half-closed door, asking by voice for external support. The user was awakened by the robot's request. He, then, located Giraff-X, canceled the intervention, and went back to bed leaving the robot unable to move. After 2 hours, the robot, still unable to move where the user left it, asked again the user for help to reach its docking station as the battery level was critical. The user was awakened again by the robot's voice and brought back the robot to the docking station. The following morning, USER-1 contacted the technical team, that inspected the MLS and replayed what happened with the user. This way, the cause of the failure was explained to him, and he was reassured. The technical team was able to provide additional fixes to prevent such behaviours from happening again. As a result, the user accepted the explanations and decided to continue with the pilot.

Robot Requests for Support A few days later, USER-1 contacted the technical team to report that the robot was standing motionless in the middle of the room after performing an intervention. USER-1 reported that he was not feeling confident nor safe after the previous incident. By inspecting the MLS, we discovered that the robot was working correctly and that the issue was that USER-1 was overseeing the robot's movements by standing right in the middle of the path the robot should have followed towards the docking station, blocking its trajectory and forcing it to stay motionless in that point. We instructed the user to clear the robot's path, allowing the robot to recover its motion. The robot successfully returned to the docking station and the user was reassured about the proper functioning of the system. After this, we received several remarks by users who signaled how, after talking to them, the robots often remained static in their position for some minutes. We then explained that it was

because they were blocking their path towards the docking station. As a consequence of their better understanding of the system, the users adapted their behaviours to avoid the repetition of the problem and they were not worried by such events.

Robot Moving while User Away USER-1 contacted us to signal that the robot was wrongfully moving around his house while he was not in, and that, for this reason, he was not feeling safe leaving his house. We inspected the MLS, through its replay functionality, and we observed that while the user was away, the robot was behaving correctly and not moving. USER-1 was referring to a one-time situation in which the robot started an intervention right before the user quickly entered and immediately after left the house for a couple of minutes. Detecting that the user was no longer at home caused the robot to cancel the intervention and to move towards its docking station. At that point, the user re-entered the house and saw the robot moving towards the docking station. After the explanation, USER-1 understood what happened and he was confident about the proper functioning of the robot.

Similar behaviour was signaled by USER-2. Upon her return home after a few days away, she signaled that she found the robot switched off in the middle of a room. By inspecting the MLS through its replay functionality, we discovered how the robot lost connection with its docking station due to an external event and tried to trigger a docking maneuver. However, as the house was in total darkness, the docking approach failed, and the robot shut down to preserve its batteries. The user was convinced by the explanation and was reassured that the robot was not moving without her approval, or in her absence.

Remote Monitoring During COVID-19 Lockdown Most of R2 pilot took place during the COVID-19 national lockdown, preventing any form of in-place support. In this particular condition, the use of the MLS proved to be extremely useful and allowed us to successfully complete the experimental campaign. During that period, users who lived alone were spending all day at home with their robots. Users were asked if they desired to continue with the pilot even in this particular situation, and all of them agreed. Thanks to the constant feedback they gave to technicians and to the use of the MLS, we were able to provide support and allow the users to successfully complete the pilot.

Moreover, USER-3 explicitly requested to have the system on and remotely maintained even after the official pilot period. This user was particularly engaged with the robot and was happy to “see the robot wandering around the house”. Overall, the user kept the system and the robot active for two additional months after the end of the pilot, providing positive feedback and reporting that the system, and the presence of the robot, “was of great support during the difficult time”.

B. Robot Acceptance Questionnaire

At the end of the evaluation period, users were asked to answer a set of questionnaires related to their experience (using a 1 to 5 Likert scale with 1 for “strongly disagree” and 5 for “strongly agree”). In Table I we show the results

Question		<i>M</i>	<i>IQ</i>
Q1	While the robot is navigating, I am feeling safe	4	3
Q2	While the robot is navigating, I am feeling comfortable	4	2
Q3	The robot is not intrusive during the environmental exploration	3	4
Q4	While the robot is navigating, I am not feeling in apprehension for the objects in the house	5	3
Q5	I don't feel pressured when the robot approaches me	5	2
Q6	Autonomous robot navigation helps me in everyday life tasks	1	3
Q7	I clearly understand when the robot is approaching me	4	4
Q8	The robot detects me quickly	2	2,3
Q9	The presence of the robot helps me in managing emergency situations with a lower level of anxiety	3	3
Q10	Vocal interface is responsive to my inputs	4	3
Q11	Vocal instructions provided by the robot are clear	4	2
Q12	Vocal reminders provided by the robot are clear	3	2
Q13	I can easily interact with the robot through vocal commands	5	3
Q14	I am feeling comfortable when interacting with the robot	5	4
Q15	When interacting with the robot, I don't perceive delays between its requests and its answers	1	3
Q16	I think that the feedback from the robot should be more informative	4	2

TABLE I: Robot Acceptance Questionnaire. *M* is Median, *IQ* is InterQuartile range.

gathered through the questions involving the robot. The proposed framework, with the use of the MLS to provide remote support, allowed participants to report feeling safe and comfortable both during the robot navigation and during the human-robot interaction, as can be seen by the particularly given answers provided to questions Q[1-5]. Despite the size of the robot, moving autonomously for a long amount of time in their own houses, users did not feel that it was intrusive (Q05). From the answers in Table I, it can be seen how the robot was accepted by the users, who positively evaluated and understood the robot behaviours. As an example, USER-1, even after the critical events reported in the previous section, answered with the highest mark to questions Q[1-5]. Despite these positive remarks, users reported that the robot should be more helpful and responsive, highlighting that there is still work to do to meet the needs of the potential end-users of SAR-based systems.

VI. CONCLUSIONS

In this work, we have presented the results obtained in a more than 180 weeks long experimental campaign during which a SAR was used to support and assist the lives of older adults living alone independently. We showed how the use of a remote MLS increased the level of control and explainability of such a complex system and, ultimately, improving the acceptance and the confidence of the end-users towards the SAR. Future work will involve a deeper analysis of the insights collected in the extensive experimental campaign, investigating the criticalities that emerged from the long-term deployment, and investigating the possibility of performing online anomaly detection and resolution of critical events [29]. This work represents an additional step leading towards the widespread adoption of SARs for independent living.

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