A preliminary field-trial investigation of enhancing a commercial telepesence robot with semi-autonomous navigation @Home

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Abstract

Recently, the market of telepresence robots has a great growth especially given the increasing demand for improving patient care by providing a direct link with doctors and caregivers. However, driving the current commercial telepresence robots seems not trivial given the limited (or even absent) robot autonomy capabilities. This paper presents and evaluates a preliminary field-trial to enhance a commercial telepresence robot with limited computational resources with a semi-autonomous navigation system. The system is designed to facilitate teleoperation by relying on enhanced robot capabilities of contextualizing the environment and the human intervention via high-level directional commands. Participants were required to drive the robot in a real house from the living room to the bedroom passing through a corridor, open space and not target rooms. The robot moved in autonomy, the participants were asked to intervene by sending commands when they thought it was necessary to complete the task. The navigation task was accomplished with success thanks to the cooperation between the *robot awareness* and the operators. Results on the human evaluation in terms of *trust* and the *workload* suggest a low level of risk perception, effort, and frustration.

Keywords

Human-mediated robot autonomy, Telepresence robots, Teleoperation

1. Introduction

Telepresence robots serve as service bodies for remote people, to allow them to experience a location without physically being present [1]. With this purpose, typically, telepresence robots rely on a video conferencing system to connect a remote person (i.e., *secondary user*), with other people, also called *primary users*, acting in the same environment of the robot. The distinctive feature of telepresence is the combination of this bi-directional audio-video stream with the teleoperation of the robot by a remote operator. This allows the *secondary user* to maneuver the robot and interact with people, resulting in a more immersive experience than other communication channels (e.g., phone or video call). This is why telepresence robots have proven to be more effective than traditional calls in many applications, including education [2, 3], entertainment [4, 5], domestic assistance [6, 7, 8], and telemedicine [9, 10]. As emerged

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particularly during COVID-19 pandemic, telepresence robots allow to break down social and relational barriers. Similarly, in elderly care and assistance [11], family members have noted the advantage of saving travel time via the robot by monitoring and enjoying anyway during the connection.

However, current commercial telepresence robots require the continuous presence of a remote and heedful human operating the robot and in charge of taking deliberative choices about its behaviors. As a result, only *manual* or *direct* teleoperation is supported, where user commands are executed by the robot without any intermediary processing (e.g., no robot's awareness, no robot's autonomy). This means, for instance, that if the user gives a "turn right" command and a table is on the right, the robot may collide or, at best, if equipped with bumpers, stop as an emergency measure. Given the absence of robot's autonomy and ability to contextualize the situation, successful interaction with telepresence robots strongly depends on two main factors: a) the level of familiarity of the secondary users in driving a robot properly, b) the prompt feedback reception during the communication to control the robotic platform coherently. In real-life applications, typically, the *secondary users* have no experience in driving robotic platforms. Therefore, a proper training phase is required especially taking into account the basic way of interfacing with the current commercial robots. Nevertheless, delivering improper (or involuntary) commands to telepresence robots is not so uncommon during interactions also with expert users, considering the delays due to a slow internet connection, as seen in recent experiments such as, e.g., [12, 13]. Finally, a third limitation arises from the lack of any level of autonomy and context awareness in the current commercial telepresence robots. Even in the best scenario, where a *remote user* has perfectly learned to control the robot and the internet connection is sufficiently stable, the continuous focus of the remote operator is required to deliver the expected command. Therefore, teleoperating these robots one at a time can be demanding and frustrating as already reported in previous studies [14, 15, 16]. Controlling multiple telepresence robots simultaneously seems to be out of reach for a single remote human.

In this paper, we investigate the feasibility to enhance a commercial telepresence robot with limited computational resources with a semi-autonomous navigation to facilitate remote teleoperation in a domestic environment from only high-level directional commands delivered by the operator if needed. Indeed, we hypothesize the operator would like the robot to be endowed with a certain level of autonomy by perceiving the full control of the platform. Thus, we tested the proposed human-mediated autonomy system in a preliminary field-trial experimentation in a real home characterised by doorways, corridors and multiple rooms with the typical domestic furniture and with the available network connection (e.g., no network enhancement). We focus on analysing the robot's motion, the human intervention and the human evaluation in terms of *trust* and the *workload* required during the interaction.

2. RELATED WORK

Over the years, *manual* teleoperation has been widely assessed also in the domestic scenario. For instance, many research projects, including GiraffPlus[1],SYMPARTNER[2], ExCITE[3] have evaluated the robustness and the impact of using such platforms to monitor elderly people at home as integrated care services [17, 18, 19]. Recently, with the same purpose of visiting elderly people at home, Fiorini et al. [12] tested the technology readiness level of a commercial telepresence robot Double without any kind of environment contextualization and assistance and after training the formal caregiver to teleoperation in a lab setting. More advanced are the services proposed in the previous projects SERROGA[4], RAMCIP[5] and SYMPARTNER[2], EnrichMe [20], that aim at modifying the robot's navigation according to different situations including the person search, detection of a fallen person, reaching a goal, etc. Despite the advancements and the tests in the ecological scenarios, the proposed systems need advanced and powerful hardware that is not comparable with the commercial telepresence platform that we target in this work. Moreover, in their experimentations, the robot acts in autonomy without mediation from the operator. Our system is designed to be lighter and to run in a low-cost robot and, therefore, is more similar to the one proposed in [21] for the Giraff-X robot. Indeed, both systems rely on the ROS *navigation stack* at low-level for handling the robot's motion and computing the robot's trajectory. However, differently from [21], herein, we exploit a human-mediated autonomy system where the robot's navigation is influenced both by the user's commands and the robot's awareness.

3. HUMAN-MEDIATED AUTONOMY SYSTEM

3.1. The commercial telepresence robot

In this work, we use Ohmni robot[6] by OhmniLabs shown in Figure 1a, that we have already exploited in the role of a companion and coach for cognitive and physical exercises in [22]. It is a differential mobile robot endowed with two RGB cameras (specifications: 2MP as resolution, 3.0 micron as pixel dimension, and 5865 x 3276 um as sensor's dimension), placed on the top of robot's tablet, and, the *Navigation Camera* under the robot's neck. The streaming video from both cameras is used as visual feedback for the operator driving the robot. Furthermore, the Ohmni robot is equipped with a 2D lidar (i.e., Rplidar A1: 360 °, 12 m range, 1 °as angular resolution) for *obstacle avoidance*. Given the low-cost, the Ohmni robot is more affordable than other commercial robots. In addition, its limited computational resources make more challenging the technological transfer of advanced navigation services as the ones investigated in this work. Specifically, the Ohmni robot is equipped with Intel Atom X5 Z8350 as processor with 1.92 GHz, with 4 cores, DDR3L memory with 2 GB.

[1]https://cordis.europa.eu/project/id/288173
[2]https://www.sympartner.de
[3]http://www.aal-europe.eu/projects/excite/
[4]https://cordis.europa.eu/project/id/288173
[5]https://cordis.europa.eu/project/id/643433
[6]https://ohmnilabs.com/products/ohmni-telepresence-robot/

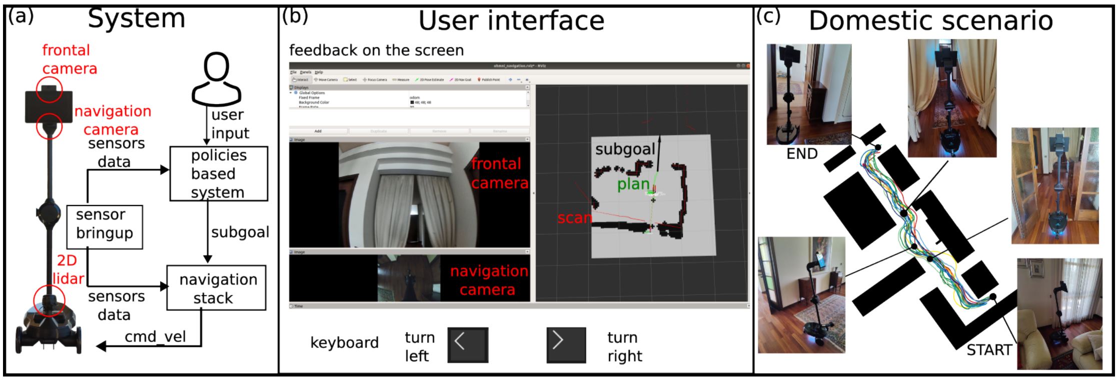

Figure 1: (a) The system composed of the commercial telepresence robot Ohmni endowed with two RGB cameras and a 2D lidar; the human who can deliver directional inputs; a semi-autonomous system based on *policies* on the top of the low-level *ROS navigation stack* for the robot's *context-awareness*. (b) The user interface. On the screen, the user receives the visual information as a feedback and provides directional inputs to the robot via keyboard. (c) The domestic scenario where the navigation task was performed and the robot trajectories during the experiment. Participants were required to drive the robot from the living room to the bedroom passing through a corridor, open space, and other not target rooms.

3.2. The semi-autonomous navigation system

The commercial Ohmni robot was endowed with a semi-autonomous navigation system based on two main components in Figure 1a: (a) a *policies*-based system in charge of computing the robot's target direction according to the context awareness from sensors' data and the direction commands from the human; (b) the ROS *navigation stack*[7] for *Simultaneous Mapping and Localization (SLAM)* and motion planning. The first component returns a *subgoal* (i.e., the arrow in Figure 1(b) which is the most probable position toward moving from the current robot's context awareness. Once computed the *subgoal*, the *navigation stack* determines the best trajectory along which the robot can move in autonomy. The robot's context awareness is modeled as probabilistic maps as proposed in [23] and previously tested in a lab setting with a brain-computer interface as user interface for delivering inputs. In this work, instead, the human delivers directional commands via keyboard when necessary. Given the higher interaction rate of the keyboard interaction, the *subgoal* is updated more frequently based on a fixed frequency (i.e., 20 Hz) and every time the human delivers a command to ensure reactivity. in addition, in this work, the probabilities maps are modified based on:

- the distances from the obstacles: the probability is inversely proportional to the closest distance of each detected obstacle to avoid collisions;
- the human's inputs: the probability exponentially increases in the quadrant associated with the command's direction;
- the robot's orientation: the positions in front of the robot get higher probability than the other (e.g., exponential weight based on the angle between the robot and the position).

[7]http://wiki.ros.org/navigation

As regards the computation of the robot's trajectory, the combination of the *Timed Elastic Band*[8] for the local planner [24] and Dijkstra's algorithm for the global planner determines the speed commands for the robot. We chose *Timed Elastic Band* than *Dynamic Window Approach* planner in the navigation stack because it made the robot reach the goals smoothly in preparatory tests for the experiments, probably due to the differential robot's base.

Given the multiple displacements that arise in a domestic environment, the robot does not rely on a global map of the house, rather it exploits the local occupancy grids computed in real-time based on the 2D lidar detections (see Figure 4b).

Both modules of the semi-autonomous navigation, implemented inside the Robot Operating System (ROS) ecosystem[9], were deployed on the Android based Ohmni-robot by using Docker[10].

3.3. The user interface for the robot teleoperation

The user interface presents the following information (see Figure 1b) that is displayed on an external screen for the operator: a) the streaming video from both robot's cameras (the frontal and the navigation areas), b) the surrounding map that is created in real-time while the robot is moving (i.e., the obstacles are marked in black), c) the *subgoal* indicating the direction towards the robot is navigating and d) the path plan returned by the ROS *navigation stack* the robot follows. The user can intervene by sending high-level directional commands, *turn left* and *turn right*, by pressing the corresponding arrows keys on the keyboard.

4. EXPERIMENT

4.1. Participants

Three participants (age = 40 ± 16.46, 2 female) accepted to take part in the experiment. The experiment was conducted in accordance with the principles of the Declaration of Helsinki. Only one has previously teleoperated robots.

4.2. Investigated Metrics & Data Collection

In this study, both quantitative metrics based on the data collected by the robot during the interaction and human evaluation based on a questionnaire administrated to the participants were assessed. Specifically, we evaluate: a) the robot's trajectory, b) the time required to perform the experiment, c) the number and the kind of human intervention (e.g., high-level directional commands). As regards the questionnaire, the metrics investigated in this study were related to the trust and the workload in teleoperating the robot. With this purpose, we adapted the *Human-Computer Trust Model (HCTM)* from Gulati et al. [25] and the *NASA Task Load Index (TLX)* from Hart and Staveland [26]. The detailed questions are reported in Table 1. Finally, we asked via an open question if they would like to provide suggestions/qualitative feedback about

[8]http://wiki.ros.org/teb_local_planner
[9]https://www.ros.org/
[10]https://www.docker.com/

Table 1
The questionnaire administrated in this study. Items were rated on a 7-point Likert scale ranging from 1 = Strongly disagree to 7 = Strongly agree.

Risk perception
Q1. I believe that there could be negative consequences when using the robot
Q2. I feel I must be cautious when using the robot
Q3. It is risky to interact with the robot
Q4. I feel unsafe to interact with the robot
Q5. I feel vulnerable when I interact with the robot
Benevolence
Q6. I believe that the robot acts in my best interest
Q7. I believe that the robot does its best to help me if I need help
Q8. I believe that the robot is interested in understanding my needs and preferences
Reciprocity
Q9. When I deliver a command to the robot, I expect to get back a knowledgeable and meaningful response
Q10. When I deliver a command to the robot, I believe that the robot gets an answer
Competency
Q11. I think that the robot is competent and effective in navigating in the space
Q12. I think that the robot performs its role very well
Q13. I believe that the robot has all the functionalities I would expect
General Trust
Q14. If I use the robot, I think I would be able to depend on it completely
Q15. I can always rely on the robot for guidance and assistance during teleoperation
Q16. I can trust the information presented to me by the robot via the interface
Mental demand
Q17. How mentally demanding was the task?
Temporal demand
Q18. How hurried or rushed was the pace of the task?
Performance
Q19. How successful were you in accomplishing what you were asked to do?
Effort
Q20. How hard did you have to work to accomplish your level of performance?
Frustration
Q21. How insecure, discouraged, irritated, stressed, and annoyed were you?

the overall system. All the data were collected, processed, and stored according to the GDPR (Regulation EU 679/2016).

4.3. Protocol

After signing the consent form, the system was introduced to the participants. The navigation task was verbally explained while walking in the domestic environment to make participants aware of the navigation area. Specifically, the participants were required to drive the robot from the living room to the bedroom at the end of a corridor (see Figure 1c). On the sides, there are multiple opening areas and other rooms. In our protocol, the robot did not know any information on the navigation task a priori (e.g., the final destination), therefore the intervention of the humans is required when the autonomous robot's behavior is not in line with his/her will. We design the task experimented in this work, in order that the human intervention is required to reach the target room to test the semi-autonomous capabilities of the system. To get familiar with the system, the participants tried to navigate the robot in an initial *familiarization run* that was not recorded. Then, participants were asked to perform the navigation task per five runs (i.e., repetitions). In each run, the participants sat in a closed room and did not see the physical robot navigating. Participants only received the stream video cameras, the robot's position in a real-time built map, and the *subgoal* computed by the system toward the robot was moving (see Section 3.3) as a feedback.

5. RESULTS

5.1. Navigation Performance & Human-Robot Interaction

All the participants carried out the five runs with success by making the robot reach the destination without causing any damage. Figure 2 represents the human's intervention in terms of *turn left* and *turn right* commands during the teleoperation along the robot's trajectories. The time for delivering commands appears consistent with the required navigation task given the robot's motion. Instead, the robot would prefer moving toward the open spaces as emerged from the trajectories (e.g., notice the curve on the left). Nevertheless, the robot's trajectories were reactively corrected thank to the user's input. Despite the tendency of moving far from obstacles, in this domestic scenario with very tight spaces, we notice that the robot's trajectories appear close to obstacles especially in two main points that correspond to a passage through a door connecting the living room to the corridor and one passage through curtains in the middle of the corridor. In addition, during the experiment, we experienced that the curtains were not always detected by the lidar (i.e., the obstacle was not perceived by the robot), for which subject S1 encountered one collision with them in the fourth run. Given this result, in the future, the system should be strengthened by introducing the semantic information from the robot's cameras. However, the robot was smoothly able to navigate up and down two different carpets in the corridors. As regards, the number of commands, we can notice different behaviors among the participants. Specifically, by analysing the number of commands, we achieve that S1 delivered on average 9 ± 2, S2 27.80 ± 10.47 and S3 13.20 ± 1.92 inputs. While the results of $S1$ and $S3$ are comparable, it seems that the subject S2 would like to have more control over the robot's motion and trusts less in the robot's capabilities of computing the *subgoal* according to the context by intervening even when it is not strictly necessary. However, this different behavior did not excessively affect the time to complete the task that is shown in Figure 3. On average, the navigation task was completed in 168.36 s ± 19.38 by S1, 217.34 s ± 54.00 by and 153.66 s ± 32.71 by S3. In addition, the percentage of the number of the left commands over the total was consistent among the participants: 35.50% ± 5.20 for S1, 33.87% ± 12.26 for S2 and 27.84% ± 8.74 for S3.

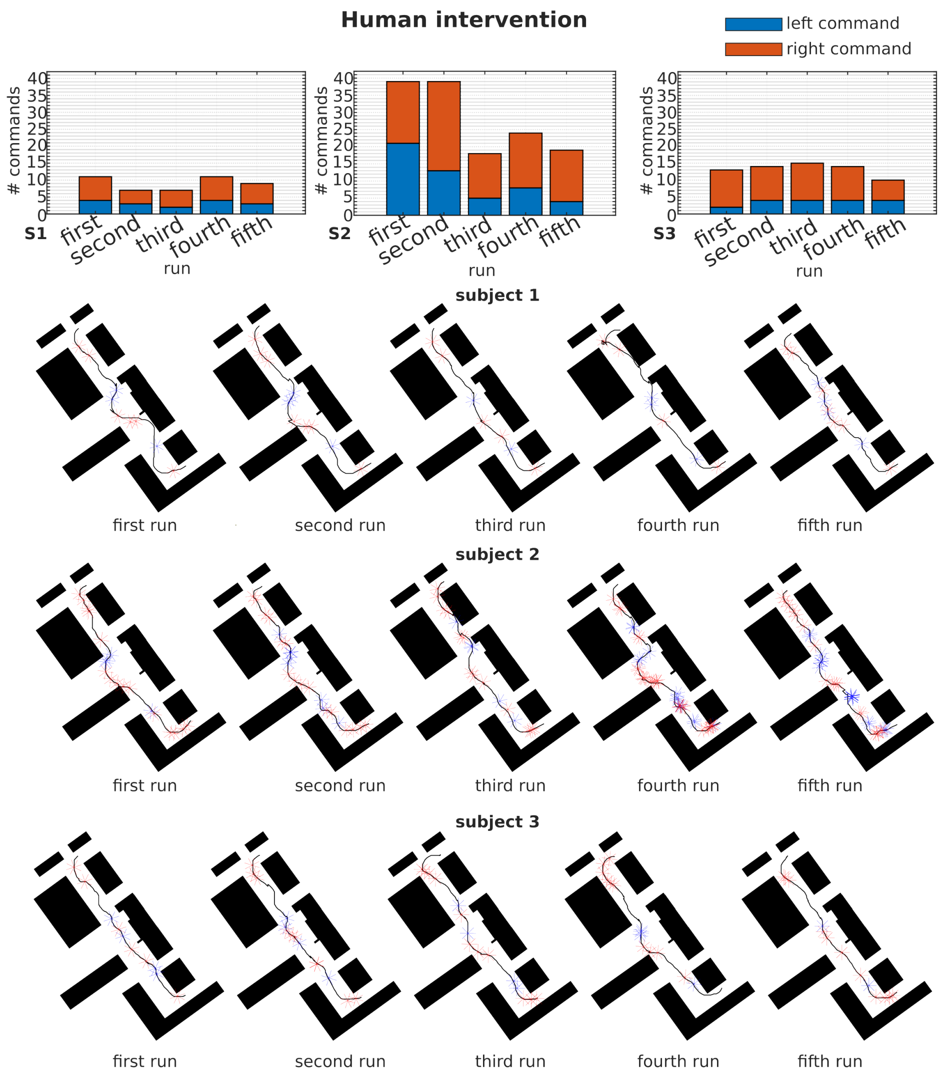

Figure 2: (Top) The number and the kind of commands delivered by each subject during the experiment. The blue indicates the *turn left* commands, while the red the *turn right* ones. (Down) The plot of the robot's trajectories per run and per participant. The delivery of both classes of commands is represented with respectively blue and red asterisks.

5.2. Human evaluation

This section presents the results from the questionnaire administrated to the participants at the end of the experiment (i.e., after completing the five runs). The results per each subject are shown in Figure 4. The first five columns represent the scores of the sub-scales of the *Human-Computer Trust Model (HCTM)*, while the last ones are related to the *NASA Task Load Index (TLX)* (see Section 4.2). The average score for each item in each sub-scale of the *Human-Computer Trust Model (HCTM)* is computed. It can notice that, overall, the level of *risk perception* was very

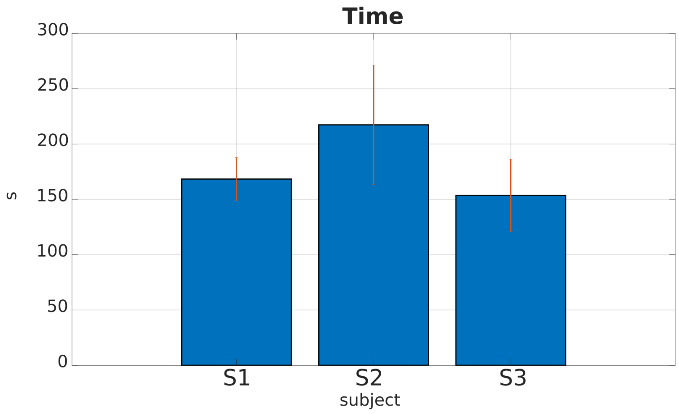

Figure 3: Average time required to complete the runs by participant. The average and the standard deviation (SD) are represented per each subject.

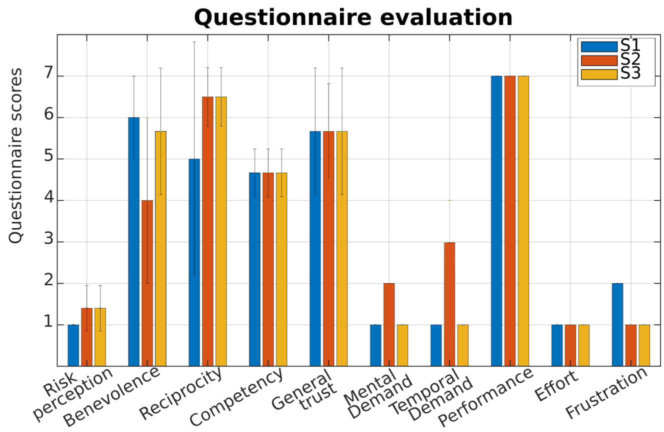

Figure 4: Questionnaire evaluation. The average scores and standard deviation (SD) for each sub-scales of the *Human-Computer Trust Model (HCTM)* and *NASA Task Load Index (TLX)* are reported per each participant.

low (i.e., S1: 1 ± 0.0, S2: 1.40 ± 0.55, S3: 1.40 ± 0.55). In terms of "collaboration", the scores are medium/high by focusing on the *benevolence* (i.e., S1: 6 ± 1.0, S2: 4 ± 2.0, S3: 5.66 ± 1.53) and the *reciprocity* (i.e., S1: 5 ± 2.83, S2: 6.50 ± 0.71, S3: 6.50 ± 0.71). In terms of *competency* of the system, all the participants expressed a neutral opinion (S1, S2, S3: 4.67 ± 0.58). Finally, the score of the *general trust* are medium/high (i.e., S1: 5.67 ± 1.53, S2: 5.67 ± 1.15, S3: 5.67 ± 1.53).

As regards the *NASA Task Load Index (TLX)*, the *mental demand* appears low (i.e., S1: 1.0, S2: 2.0, S3: 1.0). The feedback about the *temporal demand* is contrasting among the participants (i.e., S1: 1.0, S2: 3.0, S3: 1.0). In line with the successful accomplishment of the navigation task, the *performance* score was the maximum for all the subjects. Finally, the level of the effort (i.e., S1, S2, S3: 1.0) and the frustration seem low (i.e., S1, 2.0, S2: 1.0, S3: 1.0).

5.2.1. Qualitative feedback

In this section, we briefly report the qualitative feedback provided by the participants. S1 revealed that experienced possible delays in the sending of the commands during the experimentation. This aspect could be due to the low-speed connection. Furthermore, S1 mentioned that would like to have additional feedback to know if the command is received by the robot and then implemented. Instead, S2 would prefer to increase the robot's speed. In addition, S2 reported that would like to add further functionalities to the robot, for instance using it to transport objects among the rooms. However, despite her inexperience, S2 told that was able to orient herself well thanks to the combined visualization of the position of the robot on the map and the streaming video of the cameras.

6. DISCUSSION & CONCLUSION

This paper presents a pilot experiment in the field to investigate the feasibility of enhancing a commercial telepresence robot with few computational resources with semi-autonomous navigation and collect the preliminary feedback related to *trust* and the *workload* required during the teleoperation. Indeed, with respect to previous works, herein, we focus on a human-mediated autonomy system where the user intervention through high-level commands is required to finalize the navigation task. In this way, the human can keep the perception of having full control of the robot but with limited workload, since the robot moves in autonomy as default by handling the *obstacle avoidance* and *planning* its motion. From this point of view, despite the very small samples, we noticed different attitudes among the participants in terms of human intervention (S2 vs. S1 and S3). These results were confirmed by the questionnaire evaluation. The *mental workload* for S2 was higher than the other two subjects. However, we can notice that in the last runs the number of inputs decreases which might indicate a higher level of trust and familiarization with the system at the end. Interestingly it is also the difference in the *temporal demand.* Moreover, S2 qualitatively proposed to increase the robot's speed. As regards the remaining scales, the results are quite consistent among the participants suggesting a low level of risk perception, effort, and frustration. Further tests are needed to validate the system with more participants, once modified based on this emerging qualitative feedback and to compare the performance with other semi-autonomous approaches.

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