The MORPHIA Project: First Results of a Long-Term User Study in an Elderly Care Scenario from Robotic Point of View

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Abstract

In an aging society, efficiently organizing care taking tasks is of great importance including several players (here referred to as caregivers) like relatives, friends, professional caretakers, employees of retirement homes, clubs and so on. Especially for long-distance relationships, this can be burdensome and time-consuming. While supporting devices, like mobile phones or tablets, are slowly reaching the elder community, the drawbacks are obvious. These passive devices need to be handled by the elderly themselves, this includes an proper understanding of the operation, remembering to charge the devices, or even to hear incoming calls or messages. In the project MORPHIA, we target these drawbacks by combining a social communication platform on a tablet with a mobile robotic platform that can be remote-controlled by all mentioned actors of the supporting network or actively deliver messages emitted from the network. In this paper, we present the first stage of our demonstrator in terms of implemented hard- and software components. Since the price is a key factor for acceptance of such a system in the care community, we performed a technical assessment of these components based on our findings during the development process. In addition, we present the results of the first user tests with 5 participants over two weeks each between August and November 2021 (two further test iterations are planned for 2022 and 2023). This includes general usage of specific robotic services as well as technical benchmarks to assess the robustness of the developed system in domestic environments.

1 Introduction

Robot projects in elderly care scenarios of the last decades focused on various tasks, ranging from health and reminder services over cognitive stimulation to safety monitoring [1, 2, 3, 4]. Also telepresence tasks have widely been studied [5, 6]. However, for the best of our knowledge, none have included large and diverse groups of caregivers to the user trial period, i.e. relatives, friends, or commercial caregivers for example. In our MORPHIA project[1], we address the question of how "Good Care" can be supported by individualized communicative and emotional support through a robotic platform that enables telepresence of the diverse caregivers by the robot (see Fig. 1). Reminder messages can be triggered or scheduled by the care network, and in reverse, notifications of specific situations, such as absence, inactivity (e.g. sleeping), or falls of the the person to be cared for can be transmitted to the network. Since our study design consists of three consecutive long-term user trials, with increasing duration and levels of complexity, we follow an iterative development model with two opposing objectives in terms of the used hardware setup and available robotic skills. On the one hand, we have installed powerful hardware on the robot in combination with an edge server, which gives us the necessary computational power for new robot functionalities and powerful perception and navigation algorithms during the project's term. On the other hand, the project is targeting a low-cost system to increase its market suitability and user acceptance. To get both objectives in common, we performed a technical assessment of the robot system after the first test period, to identify system parts which can be removed without affecting the overall functionality in the second and third test period. As mentioned above,

Figure 1 Scene from our target scenario where an elderly person is on a video call with a relative.

This work has received funding from the German Federal Ministry of Education and Research (BMBF) to the project MORPHIA (16SV8426).

[1] http://www.morphia-projekt.de/

	[2] **SERROGA**	[7] **DOMEO**	[3] **SYMPARTNER**	[8, 9] **SocialRobot**	[10] **MobiKa**	[11] **Hobbit**	[12, 4] **MoveCare**	[13] **Lio**	[14] **ENRICHME**	[15] **AMIRO**	**MORPHIA**
Autonomous Navigation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Telepresence Navigation	✓	✗	(✓)	✗	✗	✗	✓	✗	✗	✗	✓
Person Detect.	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓
Person Re-Identification	✗	✗	(✓)	✓	✗	✗	✓	✓	✓	✓	✗
Following	✓	✗	(✓)	✗	✗	✓	✗	✗	✗	✗	✓
Transportation	✗	✓	✗	✗	✓	✓	✓	(✓)	✗	✗	✓
Object Manipulation	✗	✗	✗	✗	✗	✓	✗	✓	✗	✗	✗
Smart Home Sensors	✗	✗	✗	✗	✗	✗	✓	✗	✓	(✓)	✗
Speech Recognition	✗	✓	✗	✓	✗	✓	✓	✓	✗	✓	✗
Gesture Recognition	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗
Emotion Recognition	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗
Fall Detection	✓	✗	(✓)	✗	✓	✓	✗	✗	✗	✗	(✓)
Mobility Coach	✓	✗	✗	✗	✗	✗	✓	✓	✓	✗	✗
Video Calling	✓	✓	✓	✓	✓	✓	✓	✗	✓	✗	✓
Entertainment	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗
Reminders	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓
Low-cost focus	✗	✗	✗	✗	✗	✓	✓	✗	✗	✗	✓
Tests in uncontrolled environments	✓	✓	✓	✗	✗	✓	✓	✗	✓	✗	✓

Table 1 Implemented robotic skills in comparison to the MORPHIA project. Classification to the best of our knowledge: ✓- skill was used during user trial; (✓) - skill is mentioned in the system architecture but was deactivated during user trial; ✗ - skill is not mentioned and therefore assumed to be unavailable.

the general objective of the MORPHIA project is the improvement of care through the developed robotic system with associated care network. To assess the current status of achieving these objectives, we defined several sub-research questions. From a social science perspective, this includes questions for acceptance and usability, but also the actual usage of the system by the diverse users of the care network. From a technical point of view, we are interested in the stability, performance, and functional necessity of the developed algorithms. In this paper, we are addressing the latter ones as well as the actual usage question from a technical point of view.

2 Related Work

Mobile robots in the context of elder care are often referred to as (social) assistive robots (SARs), personal care robots, home-based service robots, companion robots, and even more. They can be categorized as ambient assisted living (AAL) robots in accordance to [16]. Projects in this field of research are manifold in terms of the applied platforms, offered services, operational environments, and evaluation methodology. Therefore, in the following, we focus on approaches from the last decade which targeted user trials in uncontrolled environments (real apartments of elder users). The SERROGA project [2] aimed to have a proactive robot which was supposed to assist as a kind of secretary on the one hand and a fitness coach on the other. For technical evaluation, diverse metrics were introduced, e.g. regarding the navigation skills to assess the complexity of the seniors' apartments, but no overall usage of the provided skills was evaluated. The DOMEO project [7] especially addressed long user trials over 3 months for 8 participants, each in their own apartments. No quantitative technical evaluation was performed, but some qualitative statements were made that navigation skills are far from applicability. The project SYMPARTNER [3] aimed to develop a "functional-emotional, mobile domestic robot companion for elderly people", conducting user trials with 20 seniors over 5 days each. For technical evaluation or the system maturity status, diverse navigational metrics, like successful searches or driven distance, were used to assess the robot. SocialRobot [8, 9] was a project "to provide companionship, care and socialization services via information and communications technology (ICT) to support the elderly". In contrast to the project's objectives and implemented skills, the only field trial was performed in a large entrance hall of a care center environment for 8 hours at 5 business days, and the only quantitative evaluation targeted the speech recognition module. MobiKa [10] aimed to develop a low-cost mobile robotic platform to communicate with elderly people at home, but no long-term evaluation was performed. However, the paper describes the developed system with all its features, but just evaluates the developed method to approach persons in more depth. The motivation for the Hobbit project [11] was "to create a low-cost, social robot to enable older adults to independently live longer in their own homes". The robot was evaluated in 18 single households for 21 days each. Logged data were compared with interview results, but no quantitative evaluation was performed. The commercially available robotic platform Giraff-X was technically evaluated in the MoveCare project with a single user for 9 days in [12] and 13 additional users for at least 10 weeks in [17]. Even though a novel web-based monitoring and logging system (MLS) [4] was used in this project, no further quantitative

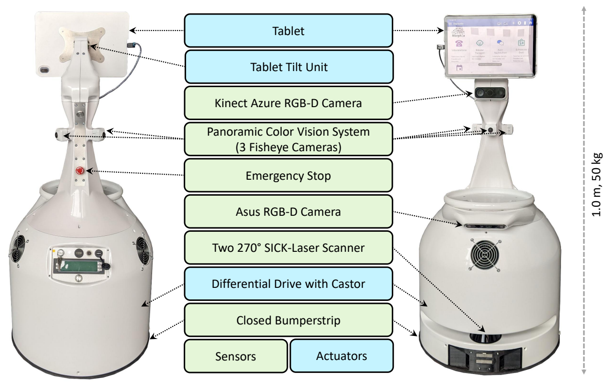

Figure 2 Developed mobile communication platform with sensors and actuators highlighted in green and blue.

evaluation was provided. The Lio project [13] developed a mobile robotic platform with a multi-functional arm explicitly designed for human-robot interaction and personal care assistance tasks. The robot has already been deployed in 7 health-care facilities, however no real uncontrolled trials were performed. Moreover, just a few technical metrics have been evaluated, like the average driven distance. The ENRICHME project [14] used a customized TIAGo iron for trials with 11 users approximately 10 weeks each. Despite various features, just the person detection and re-identification modules were quantitatively evaluated with rather small data sets. The AMIRO project [15] extended the rather narrow capabilities of the Pepper robot with improved user detection, tracking, and re-identification as well as improved navigation and speech recognition skills. For person perception and navigation, tests were performed in controlled lab environments, but no field trials have been performed yet. While all projects presented in this section have implemented a wide range of technical skills (an overview can be found in Table 1), just a few quantitative evaluations are given. The majority of them are based on user surveys that reflect subjective assessments of the few test participants. In contrast to that, in the MORPHIA project, we aim at evaluating the general usage on a quantitative basis that is presented in Sec. 6. With this information, we complement the findings of our project partners from the social science domain and are able to adaptively extend the functionality of our robot for the next test iteration. In Sec. 7, we discuss these changes. Moreover, while some of the projects target a low-cost platform to increase marketability, none have critically discussed the used hardware and the resulting consequences for marketability. We will report our findings regarding the necessary hardware specification in Sec. 5.

3 Developed System

Our robot is a modified TORY platform from the German robotics company Metralabs (see Fig. 2) with a conventional basis and a project-specific, customized top. This design choice was made to prevail security and stability of an extensively tested industrial standard robot in combination with sensors and actuators that are crucial for the services to be offered. The basis contains a differential drive on the middle axis for rotation symmetry and four castor wheels for stability. Sensors for obstacle avoidance are just applied to the front to save hardware and computational resources. A SICK S30B safety laser-scanner with an 270° opening angle is mounted at the front about 10cm above the ground plane, to restrict the maximum allowed speed by default when obstacles or persons are in the surroundings of the robot. An Intel D435 depth camera is mounted at a height of 50cm to avoid obstacles outside the laser plane. With this reduced sensor setup, rotation symmetry and restricting the navigation to avoid backwards movements are crucial to ensure collision free navigation. As mentioned, the upper part of the robot was completely redesigned and equipped with a tray for transport purposes. An Android tablet is placed on a tiltable mount for a convenient user interaction in sitting and standing poses. Moreover, since the tablet's frontal camera is the main input for video calls, the remote part from the care network is able to adjust the tilted angle of the tablet to may receive a better view into the senior's apartment. Three fish eye cameras with an 180° opening angle each are applied at a height of 80 cm to keep the user in view for social navigation and person perception tasks regardless of the robot's orientation. The Azure Kinect, mounted at a height of 1m, is used for global localization and a deeper analysis of the user's behavior utilizing the user's estimated skeleton. To execute computational expensive person detection, the robot is equipped with a NVDIA Jetson AGX Xavier mobile GPU. All other algorithms, are performed on an onboard PC with an Intel i7 6700 HQ mobile CPU. Besides the robot itself, our system consists of several other components. A a simple pushbutton based remote control can be used by the senior, to call the robot to him/her, to stop the current behavior of the robot, and to send him to the charging station. An edge server is applied as central communication device, that spans the local network that connects the robot's PC, the NVIDA Jetson and the onboard tablet. In addition, it acts as an uplink to the care network server and is suitable for handling computationally expensive algorithms that cannot be executed on the robot itself.

4 Software Architecture

Our software design follows a layered approach in accordance with [3] (see Fig. 3). The bottom hardware layer provides necessary perceptual information about the surroundings of the robot as well as an interface to the actuators. The skill layer above provides basic robotic capabilities, like person perception and robot motion. These skills are used by the behavioral layer to combine them to more complex operations, like following or searching the user. The application layer is the direct interface to the user with several custom-build android-based apps. These apps allow the user, as well as the remotely connected caregivers to access the robot's basic services, like navigation to specific points of interest in the home.

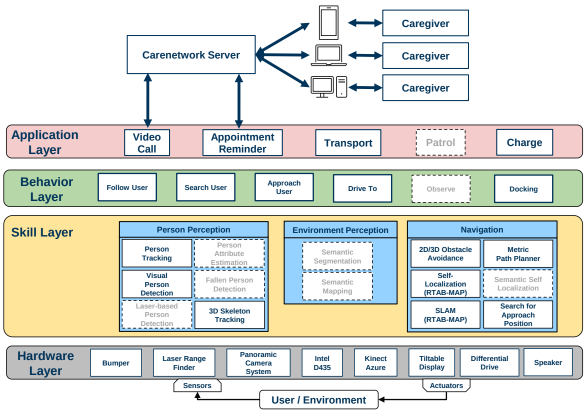

Figure 3 Overview of the developed software architecture. Implemented modules that were not actually evaluated in the user trails are shown in light gray.

4.1 Skills

The skills are the most basic modules that process input from sensors to information needed by the subsequent behaviors. For RGB-based person perception on the fisheye cameras, we rely on two efficient detection approaches - OpenPose [18] and YOLO [19], that are executed in parallel. This procedure ensures stable person hypotheses even when one detector fails. The Azure Kinect SDK is used for RGB-D person perception from which we use the estimated 3D skeleton of the user. These three detection cues are fused in our multi-modal person tracking approach [20] to consistent person hypotheses in the local surroundings of the robot (up to 5 meters). For localization and mapping, we use the SLAM approach RTAB-Map [21], that utilizes sensor input from the laser-scanner, the Azure Kinect and the Intel D435. The retrieved 2D occupancy map is taken by our navigation pilot that utilizes the E^* algorithm for global and the DWA for local path planning. Local obstacle avoidance is performed by building a local 3D NDT Map [22] that is projected to the 2D ground plane and constantly fed into the navigation stack, so the planners can take this information into account.

4.2 Behaviors

The basic robotic skills are used by the behavioral layer to provide more complex services. The most basic behavior is the "Drive to", that controls all navigation to points in the environment and returns events of success or failure to the calling parent behavior or application. The "Search user" behavior [23] uses the map from the navigation stack to iterative pick new points in the apartment where the user might be and to remember the already driven area. When a user hypothesis is found, the "Approach user" behavior [24] is triggered in a two step approach. First, the robot drives to an initial position on a circle around the user where the orientation vector of the hypothesis intersects the circle. For person orientation estimation, we rely on the skeleton from the Kinect SDK. From this initial pose, the robot can approach the senior while always presenting the tablet as main interaction device. "Follow user" is

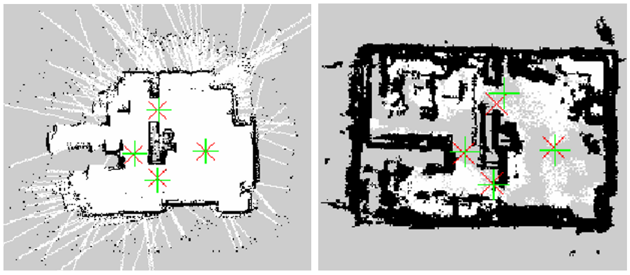

Figure 4 Occupancy grid map of our living lab, mapped with RTAB-Map with Azure Kinect and laser (left) and with Azure Kinect only (right). Crosses indicate ground truth positions (red) and measured localization (green) from one test run of our localization experiments.

implemented as described in [3] where the robots keeps a desired distance to the user. However, instead of driving to a recovery position when the user is lost, the robot now drives to the last seen position and switches to the "Search user" behavior. If a new hypothesis appears, the behavior immediately switches back to following this hypothesis.

4.3 Applications

The main module for application is the video call. A caregiver can request a remote connection to the senior, that triggers a "Search user" on the robot and brings a call notification to the front on the tablet, where the call can be accepted or denied. When the call is established, the participants are free to chat while using robotic services from the behavior layer. This includes navigation to predefined points in the apartment as well as simple navigation commands, like drive forward, turn left or right as well as to tilt the tablet angle to steer the robot remotely. Note that during all navigation the obstacle avoidance is always turned on, so the caregiver does not need to worry about collision. Furthermore, "Search user" and "Follow user" can also be triggered from the remote side, e.g. to easily drive back to the senior after observing something in the apartment. Another service that can be triggered by both the care network and the seniors themselves is the appointment reminder. In this application, a notification can be defined together with a specific point in time to be delivered. When the time has arrived, the application automatically triggers a "Search user", the robot drives to the user and gives audio advice to indicate a new incoming notification on the tablet. Another application is to send the robot to specific points in the apartment, e.g. for transportation purpose. Beside these mentioned user applications, the robot runs a self-preservation application, that monitors the current charging status to send the robot to its charging station if a critical status is reached. Moreover, the robot also drives back charging when it observes no user interactions for 15min, i.e. no clicks on the tablet, ongoing calls or signals from the remote control.

5 Technical Assessment

To assess the robustness and necessity of our system and several hardware components, we performed a number of tests in our living lab. For localization and mapping, we wanted to answer the question whether an expensive laser scanner is necessary or if it can be replaced by cheaper RGB-D cameras that are already used for person perception. To this end, we run several experiments in increasingly difficult environments, starting at our living lab (see Fig. 4), most similar to the targeted environment, over the complete map of our department to one floor of our university building. In each environment, we conducted measurements at four specific locations and averaged the Euclidean distance from ground truth to the estimated self-localizations over two test runs. For both sensor input setups, we experienced negligible differences even though the error increased with the complexity and size of the environment. In the living lab environment, the average absolute error was 13 cm with laser and Kinect and 17 cm with Kinect only. The complete department environment caused an localization error of 33 cm in average for both sensor input setups, and on the complete floor of the university building (length of more than 80 meters) the average error was 45 cm with laser and Kinect and 49 cm with Kinect only. All measurements were achieved on the basis of the different occupancy maps of the three environments previously generated with the RTAB-Map approach. Since our target environment, the private apartments of the seniors, resembles our living lab with respect to size, room number, and complexity, an average localization error of 17 cm is acceptable for our scenario. From this point of view, an expensive safety laser-scanner is not necessary for this type of application.

As mentioned in the last section, for person perception, we use the OpenPose and YOLO person detectors operation on the the RGB-images of the three fish eye cameras with an 180° opening angle. Since both approaches are relatively complex, we used TensorRT to speed up execution times. With this optimization and an image scheduling, that ensures that every camera is equally often processed, we achieve a detection frame rate of 4Hz per detector on the applied NVIDIA Jetson. This is a suitable frame rate to perceive persons in the surroundings of the robot with its embedded hardware. So for the person detection task alone, we currently need no external computational resources. Unfortunately, the Kinect SDK is currently not available for the Jetson's ARM architecture and needs a powerful GPU. Thus, it has to be outsourced to the edge server. However, the Kinect's skeleton is currently just utilized for the person orientation estimation to approach persons frontally. Since this skill is just a minor one, our current high performance edge server can be replaced with a more lightweight PC.

6 First Phase of User tests

From August to November 2021, we conducted the first iteration of three long-term user studies with five elderly participants over two weeks each. Two robots with identical hard- and software were deployed in parallel. After one day of installation and another one to introduce the system to the test participants, the robot remained in each senior's home for 13 days, and the seniors were alone with the robots during these days without presence of any supporting staff. When operating difficulties or technical issues occurred, technical support was provided by phone, remote access to the robot or, in rare cases, on-site. In addition to the technical support, two surveys were performed by our project partners from social sciences, one in the middle and one at the end of each trial. Beside this, the robot remained at the senior without any further intervention from the project staff. After the final survey, the robots were removed from the seniors' apartments on the last day of the second test week, which gave us a total effective test time of 13 days per senior. To visualize log data and to gain insight into the use of the robot and the implemented communication system and possible malfunctions of both, we developed a specific evaluation and visualization tool (see Fig. 5). From the logs, we were able to extract metrics describing the usage of the robot and the communication system, such as driven mileage, uptime, number of user searches, number and duration of video calls, calendar and message board usage, and so on. Results achieved during this first user test can be found in Table 2.

6.1 Long-Term Stability

Long-term stability of a robotic system is a crucial feature for user acceptance, yet hard to achieve for systems in development. In [7], for example, this issue was bypassed by instructing the user to regularly restart the robot. To measure the system stability, we used the classification scheme from [25], where failure cases were categorized from *U1 : uncritical - the application can handle problems by itself* over *U2 : critical - it needs intervention from a remote operator* to *U3 : very critical - the system needs to be restarted*. To achieve a high level of autonomy, we implemented a monitoring module that observes the update of data crucial for functionality. This mainly includes data from sensors, person hypotheses, and localization updates. If such an uncritical error is observed, the application is automatically shutdown and immediately restarted. The results can be found in Table 2 in the lines automatic recovery and manual restarts. It can be seen, that our robot with ID 1 generated more critical failure cases (30 manual restarts) than the robot with ID 2 (0 manual restarts), even though they were identical with respect to hardware and software. This is also reflected in the different operating time, while robot 2 achieved an uptime of above 90% during the trials, robot 1 was just operational 39% of the test time. The same pattern applies to mislocalizations, while robot 2 just experienced 6 wrong localization hypothesis over a test period of one month, robot 1 was mislocalized 72 times. This was most likely due to the unavailability of sensor data, which we discuss in the following. One of the critical failure cases was caused by overheating of the robot, which resulted in the robot emitting annoying warning sounds. This error case is particularly interesting because it never occurred

User ID	1	2	3	4	5
Test period	20.08 - 3.09	18.9 - 1.10	18.9 - 1.10	16.10 - 29.10	16.10 - 29.10
Robot ID	1	1	2	1	2
Effective test time	13 days	13 days	11 days*	13 days	13 days
Automatic recovery	597	806	58	1073	69
Manual restarts	11	6	0	13	0
Uptime total (days:hours:min)	5d:11h:32m	3d:01h:30m	10d:01h:46m	6d:12h:49m	12d:11h:33m
Uptime %	42%	24%	91%	50%	96%
Mislocalizations (total / per day)	20 / 1	6 / <1	3 / <1	46 / 4	3 / <1
Video calls (total / per day)	30 / 3	14 / 1	34 / 3	34 / 3	25 / 2
Total call time (hours:mins:secs)	1h:42m:56s	0h:33m:34s	3h:54m:43s	1h:48m:56s	1h:17m:39s
Notifications delivered	0	1	2	0	0
Driven distance (total / per day)	516m / 43m	538m / 44m	566m / 47m	962m / 80m	705m / 58m
Searches (total / per day)	100 / 8	33 / 3	161 / 13	353 / 30	84 / 6
Follows (total / per day)	4 / <1	25 / 2	21 / 2	21 / 2	2 / <1

Table 2 Usage analysis of the implemented skills for the first test iteration. General information about the specific test runs (top). Metrics regarding the system stability (middle). Usage metrics of the implemented technical skills (bottom). *Reduced test time due to a short vacation.

in the previous stress tests, as it only occurred when the robot was constantly charged for several hours without being used. However, we resolved this issue by enhancing the air ventilation with insertion of holes in the casing during the initial test period, so this problem did not affect subsequent tests. The other critical errors were mainly caused by hardware failures of the Jetson and Azure Kinect devices. Both devices tended to fall into an unrecoverable error state during prolonged operation, which needed a restart of the robot performed by the senior. After the trial period, we analyzed the issues of robot 1 and found the solution by powering the Jetson with 19V instead of the 12V during the trials, even though the Jetson specification allows a range of 9V to 20V. For the Azure Kinect, we applied an additional power supply besides the single USB-C data and power cable, which worked well on robot 1. With this configuration, the overall stability seems to be more reliable, but the concrete proof has to be provided in the upcoming second test iteration.

6.2 Skill Usage Analysis

Since the stability of the system obviously has a big impact on the overall uptime of the system, the general usage in our first test was indifferently affected by this, which is quite interesting. Results can be found in Table 2 (bottom row). The average video call time was 11min per day for the more stable robot 2 and 7min for robot 1 respectively. The average driven distance per day was almost equal with 53m for robot 2 compared to robot 1 which drove 52m. The same holds true for performed follows (robot 1: 1.3, robot 2: 0.9 per day in average), searches (robot 1: 12, robot 2: 10 per day in average). Looking at these values from a project perspective, the video call skill was used 2.1 times per day, while one call lasted about 4 min in average. Although there are no comparative values available in the literature, these values do not yet suggest a deeper impact on the care process targeted by our project. Here, one of the reported issues is the relatively large amount of time the robot needed for searching the user in the whole apartment until s/he was approached. This occasionally resulted in the caregiver dropping the call because he or she did not receive any feedback on the progress of the search. The driven distance per day was 54 m per day in average, which is also relatively low compared to the SYMPARTNER project [3] with 150m per day and the SERROGA project [2] with 270m per day, even though the trial times were lower in both projects. In comparison to the Lio project [13], where a driven distance of 1.4km per day was reported, this result is even more sobering, even though Lio was tested in a wider clinical environment. The ability to send notifications to the senior was also hardly used. Up to this stage of work, the results obtained show that the current functional scope of our system is not yet sufficient to provide enough services suitable for everyday use that can improve the care of the elderly. To reach this goal, we aim to enrich the system with further functionalities that are discussed in the next section.

7 Conclusion & Future Work

The evaluation of the first iteration of user tests has shown that we have not yet reached the objectives we targeted with the MORPHIA project, however, we used the gained insights for the second iteration starting in June 2022. Regarding the stability issues, we performed hardware changes described in Sec. 6.1 on all of the MORPHIA robots. Moreover, after the first iteration of trials we implemented a module that is able to detect mislocalizations by comparing the current laser scan with the internal map representation of the robot. When such a mislocalization is detected, the robot automatically asks the user, to push it onto its charging station with a known position within the map. Regarding the implemented skills, we implemented an additional chat like notification service, enabling caregivers to send short messages to the user in a uncomplicated manner. When such a message is pushed into the care network, a search is triggered to present the message to the senior. Additionally, the robot is now able to push scans

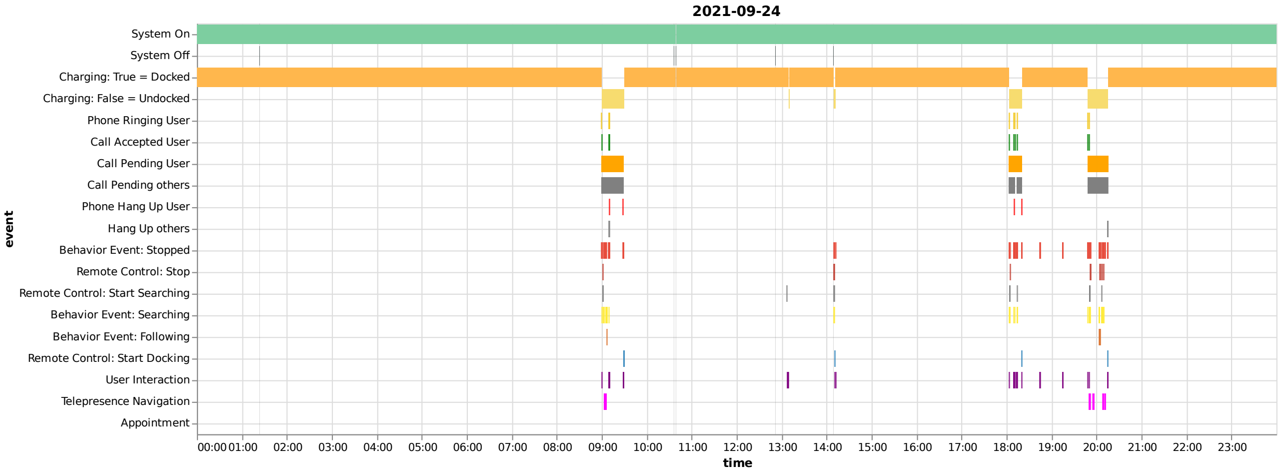

Figure 5 Usage diagram of one of our robots on a day during testing with user 3. Three phone calls occurred that day (9:00, 18:00 and 19:40), two of which involved telepresence navigation. At 14:00 the user tested the "Search user" behavior triggered by the remote control.

of documents recorded by the tablet's camera into the network, e.g. to request help interpreting medication package inserts. To reduce the relatively large search times, when delivering notifications or calls, we implemented a new "Observe user" behavior that causes the robot to stay in proximity to the user, but only if it is sufficiently charged. In addition, a progress message is now transmitted to the network during the search, indicating the part of the apartment that has already been searched. We are also currently in the development phase for enhanced environmental perception through semantic segmentation [26] and semantic mapping [27], that hopefully will provide further applications for the third iteration of user tests. From an organizational point of view, we also plan to increase the care network size with additional relatives and professional caregiver to increase the use rate of the system and see how this affects technical stability and individual care of the elderly. Here, our social science and care science partners will also draw their conclusions, which will then be the subject of later publications. With all these adjustments, we are excited to see how the use of the robot will change in the second and third user tests and what impact this will have on individual care.

8 Acknowledgement

We would like to thank all our MORPHIA partners for their contributions to the preparation and implementation of the first run of the field tests: the company MetraLabs Robotics GmbH, the company Cibek GmbH, the SIBIS Institute for Social Research, the Chair of Caring Science at the University of Osnabrück, YOUSE GmbH and Artis Service-Wohnen GmbH.

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