First results of Studying Human Robot Interaction in the Wild — The Hobbit Robot Tested by Older Adults at Home

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***Abstract*—Falls are the primary cause for older adults that make it necessary to move to a care facility. One option is to wear a mobile device, with the limitation that it needs to be worn any time while a fall happens one time a year. Together with care professionals we worked on a mobile robotics solution that does not only discover falls, but is pro-active to avoid falls in the first place. Old people rapidly realized that a robot picking up objects from the floor is a great help. While tests in a laboratory setting showed the usefulness of this function, we needed to send the robot out into the user's home to learn about the real challenges when approaching a realistic use case scenario. We present results stressing Human-Robot Interaction from a study where users tested the robot in their homes in three countries. Findings indicate that the pick-up function is highly valued, even if the robot costs go up considerably as opposed to a mobile robot without arm.**

Keywords–assistive robot, mobile manipulator robots

I. Introduction

Falls are the primary cause for older adults that make it necessary to move to a care facility. Together with care professionals we worked on a mobile robotics solution that does not only discover falls but is pro-active to avoid falls in the first place. The result is the Hobbit robot, which provides a set of functions to the user with a multi-modal user interface to realize easy to use Human Robot Interaction (HRI).

While there are many service robots targeting the application of an extended video phone, there are only a few robots including an arm to interact with the environment. The top end robot with similar functionality as Hobbit is Care-o-bot [1], which was used in the SRS [2] and Accompany [3] projects to study user interaction for bringing water and other help functions in care facilities [4]. This robot is too large to operate in homes while several of the other robots such as Giraff [5] are not autonomous and need to be remotely operated.

The main novelty of of the Hobbit robot was to bring a service robot into user's homes, that can do more than as an extended video phone that is operated by a remote user including the navigational capacity. The proposed Hobbit robot provided the following functions to the user. (1) Maintaining the user's self-efficacy is addressed with exercising cognitive and physical skills without so explicitly ad-dressing the target goal of self-efficacy (social connectedness and fitness functions). (2) Increasing the perceived user's safety is addressed by managing and keeping safe at home (emergency detection, grasping from floor, transport objects, safety check, calling the robot, pa-trolling). And (3) addressing the user's well-being to maintain a positive affect (entertainment functions). A unique setting of the Hobbit study was, that users were free to select any of the functions at any time. We summarize results related to HRI and what technical realizations proved to be useful or need improvement.

The paper is structured as follows. We proceed with a closer look and comparison to other present ongoing work and then, Section II describe the Hobbit robot in more detail and in Section III the functionality that has been implemented and that it provided to the users. Section IV summarizes the user trials, how they were conducted and what was measured. And Section V summarizes and discusses the results and first findings.

A. Related Work

Ideally robot helpers for older adults should investigate the feasibility of providing robotic assistance with Activities of Daily Living (ADL) and the extended assistance functions for Instrumental ADL (IADL). Typical functions of ADL/IADL are dressing, food preparation, eating, cleaning, and rehabilitation or direct physical exercise activities. Hobbit did not set out to address these needs, since all these capabilities are yet beyond present robot capabilities. What can be achieved relates to the maintaining and safety of the home, fitness functions, and creating positive effect with socializing functions. Another aspect is where these robots are studied. There are only very few studies that go beyond trials in care facilities and study longer durations, e.g. [6] and a recent survey in [7]. In the following, we highlight recent developments.

Today most of the other service robot projects further advance the state of the art of one specific functionality. For example, in GrowMeUp [8] the user's habits, preferences, and routines are studied using multiple sensors on the robot and the environment. The robot is a reduced PAL platform without arms from Pal Robotics [9]. As we have seen in our user experiences, relying on an external sensor network may be feasible in specially designed homes but is not welcomed by users at home and requires substantial installations and the related costs.

The EU project EnrichMe [10] also studies the use of touch screen and an augmented user interface as a follow up of the Companionable project with Robosoft and their Kampai robot. Ambient Assisted Living (AAL) functions are used by introducing Radio-frequency identification (RFID) chips into objects, something long in talk but that did not yet materialize since it requires a retrofitting of items and the similar issues regarding installations at home. The research prototype Kompai is not certified for autonomous use with persons.

Another recently started project is Mario [11]. It addresses loneliness, isolation and dementia in older persons through multi-faceted interventions delivered by service robots using AAL sensor installations. The partners will use near state of the art robotic platforms based on the Robosoft robot that is "flexible, modular friendly, low cost and close to market ready in order to realize field contributions in the immediate future". A specific feature is to allow for application development for the robot to augment its functions.

The big step forward in these projects is that the robot should be at least partially autonomous in the user's home. So far robots have been operated remotely or only for very few tasks in a home during limited time of user trials, for example in projects such as SRS, Giraff++, and RobotEra. It was pointed out by coordinators of these projects that the autonomous navigation capability as developed within Hobbit will be of great use also in these projects and beyond.

In summary, user requirements as created in Hobbit already pinpoint the primary user needs. In view of this, we will in the next sections present what we would improve over the Hobbit concept. Experience has shown and our user studies have confirmed that a modular approach with customizable features would most suitably satisfy the heterogeneous group of elderly who could benefit from the use of Hobbit robot in their homes. We present next the robot itself in more detail and then enumerate the functionality that we provided for the user trials at home.

II. The Components of the Hobbit Robot

The second prototype (PT2) of the robot platform used for the home trials has differential drive kinematics, a floor-parallel depth camera, a *head* with screens as eyes and an RGB-D camera (ASUS Xtion mounted at a height of 120 cm above ground), a touch screen in front of the torso, and an arm with a gripper. The platform implements some of the lessons learned from a previous study with an older versions of the Hobbit robot [12]. The height of the Hobbit robot is now 125 cm and it has a width of maximum 56 cm at the point where the shoulder of the arm sticks slightly out beyond the robot.

The development of the system aimed to keep hardware costs as low as possible. The intention was to study if it is feasible to provide good functionality at home even with lower cost components to come closer to the target of introducing a robot into user homes. The hardware components sum up to EUR 16.000,-, Figure 1 presents the Hobbit robot and its components. Autonomous navigation was based on a virtual laser scan. The robot was operated via a Multi-Modal User Interface (MMUI) which consisted of a Graphical User Interface (GUI) with touch, Automatic Speech Recognition (ASR), Text to Speech (TTS) and Gesture Recognition Interface (GRI). It provided entertainment (radio, music, audio-books, games, fitness function), reminders, video phone service, control of a manipulator, access to an AAL environment (e.g. call buttons), and emergency call features. The robot's functionalities included automatic emergency detection (e.g. patrolling and detecting persons lying on the floor), handling emergencies (communication with relatives), and supportive fall prevention measures (transporting small items, picking up objects from the floor, searching for objects the robot had been taught by the user).

Figure 1. The Hobbit robot and its components.

III. The Functions provided by the Hobbit Robot

In one of the first studies of its kind, a low-cost mobile social service robot with an arm that was intended to interact fully autonomously [13] over weeks was deployed in seniors' private homes, to support them with tasks and make them feel safe. Our study thus marks a major step in evaluating robotic systems under real-life conditions [14].

The selection of functions that have been implemented on the robot have been extracted from multiple interaction with users, secondary users or relatives and professional care givers. We conducted first home trials with an autonomous robot with the aim to find out what users want. Here, a lot more work is needed and recently started projects will expand our understanding. Part of this work was that we conducted two iterations of user studies and collected user requirements in [15]. These requirements give a clear picture of what older adults would want at present from a robot helper at home. Conclusions are drawn from workshops with older adults that created a longer list of requirements, which have then been ranked in studies and questionnaires, and correlated with technical feasibility given the present state of the art in service robotics. We used first user trials and lessons learned to verify the ranked requirements [16].

Before reviewing the robot system concept, let us shortly summarize the user requirements and relate them to other studies or care robots. The clear requirements formulated within the Hobbit project still hold. The main services that a home robot should provide to aid older adults target the following needs:

- Maintain the users efficacy level: this includes functions for keeping active such as

  - Social connectedness including telephone, Internet access to alternative ways of communication, such as a video call or to access weather, news and other information.
  - Physical and cognitive fitness including physical exercises that have been considered on top of the initial description of work. This includes games and playing music or video, and a function that has been surprisingly welcome by users to play the favorite radio station.
- Increase the perceived safety of user:
  - A main aspect is already the physical presence of the robot and its care functions such as seeking the user and user interaction during the patrolling function.
  - Multi-modal interaction capabilities and several ways to trigger an emergency call.
  - Pick-up of known and unknown objects from the floor which turned out be an essential aspect. The normal skepticism towards the robot went away after seeing the robot picking up an object from the floor.
  - The robot provided an additional safety check to the user, making her/him aware of hazards at home while proposing solutions or options to assist.
  - Calling the robot for help: the use of call buttons is an effective means to call the robot for any task at any time.
- Functions for the user's wellbeing: here we summarize services that are nice to have and will actually assist to accept the platform and keep it in use. In the Hobbit idea we had drawn out many of these functions as elements to make the user feel good, and possibly even create a bonding to the robot such that it is trusted and used and the previous two aspects are reached to an even better degree. Examples of these functions are:
  - A first personalization of the robot that is executed in the initialization phase. Additionally, the robot and basic guidelines for operating it are introduced.
  - Learning and finding objects is a welcome feature for the users and regarded as a great commodity.
  - An important functionality that extends the functionalities provided in Hobbit is the pick-up from high locations. Grasping objects from places high up that cannot easily be reached will be investigated in EU project Ramcip, though robot costs are expected to be considerable higher. In Hobbit we regard this functionality as a future module and a possible extension of the basic robot platform.
  - Entertainment ranging from games over music to surprising the user with the specific aim to increase user acceptance.
  - Reward functionality is a means to enhance the user binding with the hypothesis to improve the acceptance by the user.

In summary, the Hobbit robot provides a rich repertoire of functions, where several are novel and have been tested with users or at home for the first time.

IV. Design and Methods of the User Trials

We conducted user trials in Austria (seven end-users), in Greece (four end-users) and in Sweden (seven end-users). The trials with a total of 18 primary users (PU) and 16 secondary users (SU) were carried out in the homes of the users with the robot interacting autonomously for three weeks with the user. All trials took place in private homes of single-living senior adults and lasted for a total of 371 days Assessment by means of qualitative interviews and questionnaires took place at four stages of each trial: pre-trial, mid-term, end of trial, and post-trial (i.e. one week after the trial had ended). Results of the qualitative interviews as well as perceived safety measured by the Falls Efficacy Scale (FES) [17] are reported here. Out of 18 users 16 (14 female) were included for statistical analysis as two participants had to be excluded because of missing data). The mean age was 80 years, ranging from 75 to 89 years. Qualitative data was organized using NVivo (QSR International). Quantitative data was analyzed using SPSS by means of descriptive statistics and non-parametric methods (Friedman ranking-test).

A multi-method approach was applied for the evaluation of the three quality criteria usability, acceptance (including the Mutual Care concept [18]), and afford-ability. The evaluation followed a detailed evaluation plan with updates according to the inputs of the project reviewers, as well as the results of pilot user tests in their own flats. Results were gained from questionnaires, interviews, cultural probing with the participants before, during and after the trials, and continuous logging of all interaction data on the Hobbit robot.

V. Findings from the Study with Older Adults Users

As the data analysis is not yet finished we present first results and structure these into the aspects regarding the robot usage (usability, acceptance, afford-ability) and issues related to the robot hardware, software and development.

A. Results regarding Overall Robot Usage

The most important results of the user trials related to the three main quality criteria were:

- Usability: given there are no technical problems, Hobbit is easy to use and intuitive to handle. Different input modalities and flexibility was helpful for PUs. Utility of Hobbit's functions was however perceived to be lacking, often due to technical failures.
- Acceptance was ambivalent among users. The attitude towards a robot did not change significantly, and observed changes were of a negative kind. PT2 also failed to provide a significant feeling of safety and influence users' self-efficacy. Emotional attachment weakened over the course of the trials, possibly indicating the unfulfilled expectations of users and a sort of weariness from the trial procedure. What is more, reciprocity was not given for PUs, which shows that the Mutual Care approach needs some refinement to become effective.

- Afford-ability: From the experiences with PT2 in the trials, afford-ability (at a price of Euro 16,000.-) is not given for most users. Still, a reliably functioning version of Hobbit featuring a head, an arm, pick-up and learning functionality would be attractive for PUs.

From the qualitative data we extract how the different robot functions have been evaluated by the users. They highly appreciated the functions picking up objects from the floor, transporting things, detecting emergencies, delivering fitness and giving reminders. Concerning usability (also see above), they stated that the prototype was intuitive to handle but that errors in the actions of the robot led to frustration. The pick-up function, for example, was fully operational only for about 18% of the 371 days. And, if available, only about one out of ten attempts was successful. Furthermore, processing speed of the whole system was criticized as being too slow. Neither voice commands nor gestures worked satisfactorily, which is why the touch screen ultimately was used most. In summary, usability was negatively influenced by a lack of robustness. Quantitative data indicates that the perceived safety as measured by the FES did not change in the course of the trial ($p = 0.265$).

Furthermore, the concept of Mutual Care (MuC), developed to increase acceptance and use of Hobbit by older users, was found to have no effect. The reason for these unexpected results is, with high probability, to be found in the technical malfunctions of main features like *learn object* or *bring object*, many false positive fall detections as well as unreliability of most of the other commands. As reliability is a prerequisite for user acceptance, this result suggests that acceptance of a reliably working Hobbit would have been probably much higher and that a such a robot would also better have met the expectations of the users. Thus, a technically improved, highly reliable and cheaper version of Hobbit still has a high potential of becoming a useful and accepted tool in assisting senior adults at home.

B. Results regarding Technical Improvements towards Future Home Robots

While Hobbit already improved over other robots in terms of size - it is considerable smaller both in width and height than Care-o-bot - it is still too large. Robot height was found to be linked to the main use of the robot. Users would like the robot to be about as tall as when they are sitting. We closely reached this but a maximum height of 120 cm was found to be most appropriate. Robot width is constrained by the homes of older adults where space is typically limited. Hence, the platform should be smaller and has ideally not more than a diameter of 40 cm. At present this would cause considerable technical difficulties to integrate arms, batteries and drives but technology is getting close to this goal. And for reasons of easy navigation it is recommendable to give the robot cylindrical shape which renders rotating behaviors easier. Also in several cases doorways are as small as 65 cm and traversal will then be easier if not feasible. Finally, the robot arm should be completely inside the footprint of the platform when the arm is in home position, so it cannot collide with the environment when Hobbit is moving or rotating. A remaining issue are threshold. 25 mm have been found often and we used ramps to overcome these obstacles. It would be advantageous to find a simple wheeled solution to overcome smaller thresholds without any adaptations of the environment. Example solutions to cover thresholds are depicted in Figure 2.

Figure 2. Docking station (black) and the robot wrapped in plastic for temperature tests.

Hobbit's battery live was sufficient and lasted for more than eight hours of operation time. This is fully sufficient, since users will be tired of using the robot after a few hours and the robot can go and recharge. In terms of safety the robot should never be on a lower battery level, to make sure that a longer search for the user in their home when patrolling or in case of an emergency is supplied with sufficient power of the entire robot system. However, the battery status was not transparent for the user and ideally the robot would show the estimated remaining duration of operation.

A practical issue is a small docking station and reliable markers to assure highly robust docking. Figure 3 shows the docking station standing in front of the wall for best discernibility. However, due to space limits in homes it should merge as close as possible into the wall and it would be good to be able to place it freely. The procedure used to dock onto the charging station is designed for high fidelity 2D range finder sensor like lasers. Therefore, the shortcomings of the RGB-D (limited resolution, large stand-off distance) sensors apply negatively to docking as well. In addition to this, docking requires close-range maneuvering to the charging station, which due to the blind-spot of the depth stream of the RGB-D sensors means that the actual docking is done using dead-reckoning instead of more accurate localization methods. Again, a laser could solve this problem. Nevertheless, using imaging algorithms to visually detect the charging station or a distinct visual pattern above the charging station in the RGB stream of the sensors could also be used to make docking more robust by providing more accurate localization information when close to the docking station and would be the more cost effective solution.

Figure 3. Docking station (black) and the robot wrapped in plastic for temperature tests.

Another practical issues is a way to stop the robot at any time. In addition to the On/Off hardware button, there should also be a *cancel* hardware button/switch that would allow the user to cancel immediately whatever activity the robot is doing at any given moment remotely and without having to approach

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the robot. Currently, the only way the user can stop an activity is by pressing the back arrow button or kick the bumper which stops the movement, but not the running script, or turn the key of the robot which causes a complete shut-down. All of the above actions are difficult for an elderly person to perform while the robot is moving.

At night users would want Hobbit to be silent and dark, there should be no (bright) lights while Hobbit is in the charging station. The LEDs at the On/Off switches of Hobbit and the touch screen, the LEDs at the charging station and the Hobbit eyes (displays) are too bright at night when the user wants to sleep. Finally, let us investigate more closely improvements related to the active robot head, which turned out to be of great value but has scope for improvements.

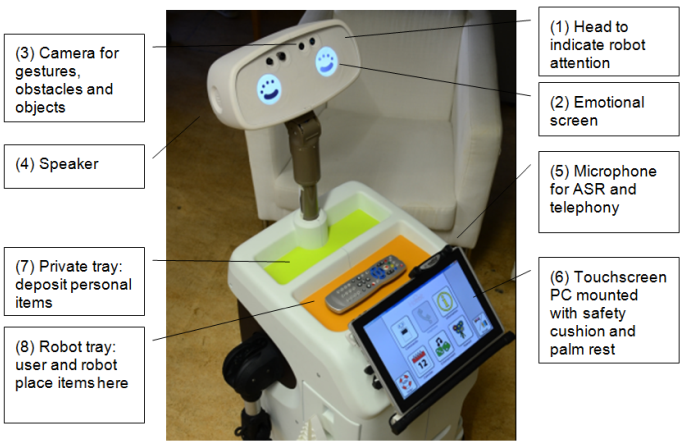

Figure 4. The upper body of Hobbit and its functionalities.

The upper body turns out to be an essential component of the robot presentation. It serves as main unit to the feeling of the presence of the robot. Figure 4 shows the upper body and head in more detail. The main functionality of the active head was to increase the field of few of the RGB-D sensor in the head and to cover with one camera functions such as obstacle detection, human detection and gesture recognition, and detecting and grasping objects from the floor. The head was designed and produced by Blue Danube Robotics [19]. It was enormously beneficial to test several head versions which lead to clear benefits of an active head. These benefits include

- Indicating robot attention to the user: the head direction naturally indicates where the robot places its attention. Users intuitively grasped that the robot is attending to them or not. This makes it extremely efficient as there is no need to present to the user in another way that the robot is busy, for example, with messages on the touch screen or spoken word.
- Extending the robot's viewing directions: the moving head allows using the camera for object search in all directions. This was used in initial search tests, where fixed robot locations and views have been used. This should be even more exploited in the future and is a powerful means to extend the operational capability of the robot without adding new hardware. One could think of it as upgrading the robot continuously with new perceptual functionalities given the same hardware.
- Obstacle detection for safe navigation: Moving the head to a looking down position allowed to reduce the blind area of the sensor and to cover a larger part of the floor. Different inclination angles were tested at the beginning in order to improve the visibility zone, also limiting obstructions caused by the tablet.

The active head has proven to be very useful in all these aspects. A limiting technical factor is the field of view of present RGB-D cameras. Typically the view is limited to $45°-60°$ horizontal field of view and a maximum of $45°$ of vertical field of view. While the pan-tilt ability of the neck enlarges this ability, the field of view for a first search is restricted.

The field of view of the Kinect or Asus sensor is $57°$ horizontally and $43°$ vertically. This limited field of view of RGBD sensors is not restricted to the Kinect but basically to all RGBD sensors available at present. Also the new Kinect, though operating on another principle, Time of Flight (TOF), has about the same field of view. Other alternatives have similar characteristics, e.g. the ARGOS 3D - P100 sensor of Bluetechnix with rather limited resolution of only 160x120, or the Sentis ToF M100 OEM plus camera that is made to fit into customer products. Another option is the Intel(R) RealSense(TM) 3D Camera (Front F200) Depth Intel RealSense F200/VF0800, yet gain with a similar field of view. The present sensor situation is even more restricted, since neither PrimeSense nor ASUS Kinect sensor are commercially available any longer.

With the tasks of viewing both the floor, obstacles, onto tables for object detection, and forward to detect persons and recognize gestures or activities, the proposed set-up is still viable, and can be improved by the addition of other sensors to increase safety. A slightly changed design with a dark face may better hide the dark holes from the camera. One way to augment the field of view is to include a wide field of view camera into the head. The human visual system covers about $180°$ horizontally. This would be of particular interest for locating the user. The head would still rotate to fixate the user, or try several fixations, until the user has been reliably detected. Again, the capability to have a gaze direction and indicate to the user where the robot attends at present comes in handy and will create the expected bonding as shown in the trials.

First work in this direction is ongoing, e.g. [20], [21]. However, there are no systems yet that would reliably and repeatedly fixate the user in an open home setting. Furthermore, only in a few works an adaptive approach to the user has been attempted and then the distance estimate was used from a laser to the single person legs in a given setting [22].

Finally, there are several practical issues that help in the design and trial phase of a home robot. It is useful to make the robot and its functionality remotely accessible via a secure Internet connection. This allows engineers to check on the platform and encountered problems without physically moving to the trial site. If issues with the hardware need to be resolved, a hull that can be easily unmounted saves a lot of effort. And there is a trade-off between simple hardware and more complex software. For example, we did not use any ultra sonic (US) sensors, which had the effect that we had to make sure that glass surfaces do not cover the full range of the height of the

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robot. Wooden frames typically produce sufficient signal in the RGB-D cameras to present no hazard. On the other hand, a few US sensors may improve the situation and may also aid in a simple check before driving backwards.

At the end, and mixing with experience from other projects, it is not sufficient to detect the floor alone for driving forward safely. While we did not encounter any dangerous situation when navigating with Hobbit, redundant perception of drivable floor is essential to assure robot safety in front of downward steps. Hole detectors based on infrared sensors and as a third measure a means to block access to certain areas in the navigation tool are advisable complimentary measures.

VI. Conclusion

The paper presented Hobbit - a robot developed and built to enable older people to feel safe and stay longer in their homes by using new information technology including smart environments (Ambient Assisted Living - AAL). The main goal of the robot is to provide a *feeling of safety and being supported* while maintaining or increasing the user's feeling of self-efficacy (one's own ability to complete tasks). Consequently, the functionalities focus on emergency detection (mobile vision and AAL, regular patrolling), handling emergencies (calming dialogues, communication with relatives) as well as fall prevention measures (keeping floors clutter-free, transporting items, staying active, fitness, and reminders). Moreover, high usability, user acceptance as well as a reasonable level of afford-ability are required to achieve a sustainable success of the robot.

We presented first results of a longer study of the robot in the wild, in the homes of 18 older adults. The study lasted for three weeks each, with another specific highlight of the study, that the robot was fully autonomous. Users could freely select what they wanted to do with the robot. While certain functionalities such as grasping objects from the floor and searching for objects did not provide sufficient reliability, other functions such as navigation, docking, entertainment, reminders, and the fitness function proved to be useful. Users saw the great potential of such a robot and very highly evaluated the capability to pick up something from the floor and to transport and find objects.

Regarding the effectiveness of HRI, the main finding is that an active head is a very helpful way to convey information about the robot and to facilitate human robot interaction itself. The active camera in the head does not only prove to be useful for obstacle detection and increasing the workspace, it turned out one of the most important means for HRI as it conveys in a very intuitive way the status of the robot. It was immediately obvious to users, that a robot looking down is busy while a robot looking up and then turning the head towards the user using head and torso detection is the trigger to start an interaction. In conclusion, the usage of active heads should achieve even more attention. Future work also considers to increase the head panning range to an owl, which would make it possible to also look behind the robot in case it needs to reverse. An issue of importance when space is narrow in user homes.

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