# Hobbit - The Mutual Care Robot

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Abstract—One option to face the aging society is to build robots that help old persons to stay longer at home. We present Hobbit, a robot that attempts to let users feel safe at home by preventing and detecting falls. Falling has been identified as the highest risk for older adults of getting injured so badly that they can no longer live independently at home and have to move to a care facility. Hobbit is intended to provide high usability and acceptability for the target user group while, at the same time, needs to be affordable for private customers. The development process so far (1.5 years) included a thorough user requirement analysis, conceptual interaction design, prototyping and implementation of key behaviors, as well as extensive empirical testing with target users in the laboratory. We shortly describe the overall interdisciplinary decision-making and conceptualization of the robot and will then focus on the system itself describing the hardware, basic components, and the robot tasks. Finally, we will summarize the findings of the first empirical test with 49 users in three countries and give an outlook of how the platform will be extended in future.

## I. INTRODUCTION

Several socially assistive robots for caring of the aging population in the domestic context have been developed as research platforms so far (e.g. KSERA [1], DOMEO [2], Cogniron [3], Companionable [4], SRS [5], Care-O-Bot [6], Accompany [7], HERB [8], and many others). Despite the volume of research and development efforts, hardly any robot really entered private households besides vacuum cleaners and lawn mowers. Developing robots for "real world environments" is a challenging endeavor. We have to consider constantly changing environments we do not know in advance and natural interaction from the user, which is hard to predict and reactions on it are hardly pre-programmable. For the development of a care robot additional challenges arise: Many older adults want to live independently at their homes and as long as possible [9]. However they themselves experience challenges in maintaining their home and the need of assistive technology [10] can be perceived as stigmatization [11].

Thus, our overall goal in the Hobbit project is to develop an affordable and highly acceptable socially assistive robot that supports older adults in staying independently at home as long as possible. One of the biggest risks for an older adult is falling and getting injured, which can cause a move to a care facility. Hobbit should reduce that risk through preventing and detecting falls (e.g. by picking up objects from the floor, patrolling through the apartment, and by offering reminder functionalities) and handling of emergency situations (e.g. calling the ambulance, offering help with rising from the floor) as a helper companion.

Socially appropriate behaviors as well as safe and robust navigation and manipulation in the private homes of older adults are to our conviction a prerequisite for getting Hobbit accepted as a care robot. Our contribution is to develop Hobbit along the Mutual Care paradigm [12], an interdisciplinary user-driven design approach based on the sociological helper theory [13]. The idea is that the user and the robot take care of each other. In other words, Hobbit should encourage the older adult also to care and help the imperfect robot, expecting that it is easier to accept assistance from a robot if the user can also assist the machine (which subsequently should also reduce the stigmatization of the technology).



Fig. 1. The "naked" Hobbit robot (left) and the Hobbit robot (prototype 1) used for the first round of user trials (right) in Austria, Greece, and Sweden.

The focus of this paper is to present the Hobbit system and the basic robot tasks that we implemented as a first step. Firstly, we will describe the robotic hardware platform. Then, we will discuss the main components: gesture recognition, human detection & tracking, grasping, and object learning & recognition. Next, the robot tasks will be presented in more detail followed by a short overview on the results of the empirical user testing, which was conducted with 49 participants at three different test sites in Europe (Austria, Greece, and Sweden). The paper is concluded with a reflection on what we have achieved so far.

#### II. SYSTEM AND HARDWARE

# A. Platform

The lower part of the Hobbit system is a mobile platform (see Fig. 2) with differential drive kinematics. It has a circular cross-section with a diameter of about 45cm. This combination allows the robot to turn on the spot within its footprint, which is important when navigating in narrow and cluttered domestic environments. The platform houses the batteries (24V, 18Ah) that power all electrical components of the robot and currently allow for an average autonomy time of three hours. An onboard PC ("XPC") runs the high-level control software of the robot. An additional controller board provides the low-level motion control for the platform, which can execute translational and rotational speed commands as well as fine positioning commands.

## B. Sensor System

Hobbit is equipped with a multitude of sensors that provide data for perception tasks. In the front of the mobile platform, at a height of 40cm, there is a floor-parallel depth camera (ASUS Xtion Pro). In the "head" of the robot, on a pantilt unit mounted at a height of 130cm, there is an RGB-D camera (Microsoft Kinect). The former camera is used for selflocalisation, the latter is used for obstacle detection, object detection, and grasping as well as human-robot interaction, that is based on depth-based human body observation and analysis (see in III-B). An array of eight infrared and eight ultrasound distance sensors in the back of the platform allows for obstacle detection when backing up. Finally, incremental encoders (odometry) on the two shafts of the drive motors allow measuring motion of the 20cm drive wheels with a resolution of  $70\mu$ m per encoder tick.

## C. Arm

The design goal for the arm was to use an affordable, lightweight robot arm with a human-like design. The so-called "IGUS Robolink", which has a freely configurable arm length due to its modular design and up to 5 degrees of freedom is used to fulfill these requirements. The arm has a weight of 1.5kg and each joint is driven by tendons. This has the advantage that the motor drives can be mounted on the Hobbit platform. The control of the arm system is done by the XPC using TCP/IP commands which are received by the motor controller.

## D. Gripper

The manipulator consists of a gripping system based on the FESTO "Finray effect". More specifically, the fingers mechanically wrap around any object shape without additional actuation. The assembled fingers on the manipulator can adjust themselves to the object by means of the "Finray effect". In combination with a simple open/close mechanism, a variety of objects with different shapes (like mugs, keys, pens, etc.) can be gripped. Due to the slip-proof materials used for the fingers, it is possible to grasp the objects reliably.



Fig. 2. Platform with 5-DOF IGUS Robolink Arm and Finray Gripper

## E. Multi Modal User Interface

The multimodal user interface (MMUI) consists of a GUI (Graphical User Interface) with touch, ASR (Automatic Speech Recognition), TTS (Text to Speech) and GRI (Gesture Recognition Interface). It provides web services (e.g. weather, news, RSS feed), video phone service (based on previous successful projects [14]), serious games, control of a manipulator, access to an Ambient Assisted Living (AAL) environment, and emergency call features.

Hobbit makes use of the MMUI to combine the advantages of the different user interaction modalities. The touch screen has strengths such as intuitiveness, reliability, and flexibility for different persons and different sitting positions, but requires a rather narrow distance between user and robot. ASR allows a wider distance and can also be used when no free hands are available, but it has the disadvantage of being influenced by the ambient noise level, which may reduce recognition performance significantly. Similarly, GRI allows a wider distance between the robot and user and also works in noisy environments, but it only operates when the user is in the field of view of the robot and is dependent on the lighting conditions.

The touch screen is mounted in an approximately 45 degrees angle and is tiltable to adapt for usage from sitting or standing position. Hobbit also provides a second small display on its top in order to present positive and negative facial expressions. Additionally, we aim at presenting affective states of the robot towards the user, e.g. by different ways of navigating the robot (approach trajectory and speed or moving the robot slowly when recharging of its battery is needed).

#### **III. COMPONENTS**

## A. Navigation

From the floor-parallel depth camera we compute a virtual 2D laser scan. The horizontal field of view is that of the depth camera (about  $60^{\circ}$ ) and the maximum range is 5m. The

virtual laser scan is used (together with odometry) for SLAMbased map-building [15] of the environment of the robot and subsequently for self-localisation based on AMCL [16]. When the top RGB-D camera is tilted downwards, it covers the space in front of and aside the robot. We apply a "v-disparity" based approach [17] to the disparity images provided by the camera in order to detect and remove the floor. The remaining disparity data represents obstacles from which we compute a second virtual 2D laser scan with a horizontal field of view of about 150° and a maximum range of 2m. This second virtual laser scan is fed into an AD\* algorithm [18] for local planning and obstacle avoidance. Finally, global planning from the current pose of the robot to the destination pose is achieved using the map of the environment and search-based planning (SBPL) [19].

## B. Human Detection and Tracking

Vision-based human observation [20] encompasses a set of fundamental perceptual mechanisms that social robots should support. The corresponding framework of Hobbit and the developed perceptual competences are presented in more detail in [21].

Based on recent advancements in the field of computer vision for vision-based 3D human observation and the availability of low-cost depth-aware sensors, like MS Kinect [22], algorithmic techniques for human pose estimation, recognition and tracking using depth visual data (e.g., [23], [24]) have become computationally cheap and readily available at realtime frame rates on conventional computers. We exploit the opportunity to set Hobbit capable of supporting a rich set of vision-assisted competences regarding both full-scale observation of a human (full 3D human body detection, localization, tracking) and short-range/close-up observation (hand/arm/face detection and tracking). To achieve these goals, we rely on RGB-D visual data acquired by the "head" sensor of the robot.

Initially, human body detection is performed for each acquired depth frame based on 3D scene segmentation and foreground detection. Subsequently, 3D body pose estimation is performed based on the body-related information that is closely related to 3D skeletal tracking. For each acquired frame, a readjustment of a fitted 3D skeletal model of the human body is performed tracking the 3D positions/orientations of basic body limbs and joints based on a kinematic model of the human body. Moreover, face detection and recognition as well as 3D head pose estimation [25] will be integrated to further enrich the information that the system extracts regarding it user.

Finally, the described functional module of the system feeds the GRI module (see III-C) to enable the vision-based modality of human-robot interaction, enhance the performance of action/activity recognition and facilitate other robot commands and useful user-driven applications of Hobbit, such as fall prevention and detection (see IV-F).

Most of the above system parts are based on computer vision algorithms provided by the NITE library [26]. An illustration of both 3D human body detection and 3D human body tracking in combination with pose estimation is provided in Fig. 3.



Fig. 3. Vision-based 3D human observation. An RGB-D pair of acquired visual data is illustrated. 3D human body detection is performed identifying a human body (green color-left depth image) and segmenting it from the background in the observed depth scene. Subsequently, 3D pose estimation is applied on the segmented body data to fit a 3D skeletal model of human body (right color image) and estimate the 3D positions/ orientations of 15 body joints (white dots) and infer the body limbs(red/ green lines).

## C. Gesture Recognition

A gesture recognition interface (GRI) has been developed as part of the MMUI of Hobbit (see II-E), to provide an additional input modality based on interpretation of physical body/ hand poses and gestures to robot commands. This type of interaction provides an intriguing and intuitive control modality for human-robot interaction that aspires to facilitate the communication of older adults with the robot and enhances its social and welfare role.

To achieve this interaction modality, a number of predefined gestures and poses can be recognized by the GRI, as a physical action-based vocabulary. Gestures are defined as a series of poses performed by the upper body parts within a time window of configurable length. The supported gestures can be briefly described as actions consisting of intermediate poses of body parts, such as "Raise hand & Push towards the camera", "Raise hand & Steady & Swipe up/down/left/right", "Raise hand & Move Cyclic/Waving/Steady", "Raise both hands & Cross hands", "Raise both hands & Steady" and "Raise one hand & Steady & Point with the other arm".

Based on depth and color visual data captured by the "head" RGB-D sensor (see II-B), a detected standing or sitting user, in the field of view of the sensor can perform any of the predefined actions. The set of predefined gestures and poses is assigned to specific commands and tasks to be intuitively executed by the robot upon successful recognition i.e., "Help-the-user" robot command is triggered after a "Cross hands" gesture is performed by the senior user and recognized by the robot. Another example regards the "Bring object" command, where a user can perform a gesture (i.e "Raise hand") to trigger the action and subsequently indicates a specific object in 3D space extending his arm to point the location of interest. Moreover, answering "Yes/No" in human-robot dialogues is feasible using GRI and mapping any of the gestures in the defined "Raise hand & Swipe" set to commands.

The implementation of the described functions relies on the open source OpenNI framework [27] and its middle-ware library NITE [26].

## D. Grasping

For grasping unknown (Sec. IV-C) and known (Sec. IV-E) objects, first the main horizontal plane, e.g. floor or table surface is detected and the corresponding points are eliminated. Clustering the remaining data delivers point clouds of objects. Grasp points are calculated with Height Accumulated Features(HAF) [28]. This technique calculates feature values based on height differences on the object and uses these feature values to detect good grasp points by applying a grasp classifier that was trained using Support Vector Machines (SVMs).

## E. Object Learning and Recognition

For learning and recognizing objects, 3D shape descriptors [29] are calculated from views of the object, coming in the form of RGB-D data from the Kinect camera in the head of the robot. Each view of the object is stored in a database [30] in the learning stage and later matched against in the recognition phase using random forests [31]. The re-training of the forest is done immediately after new views of an object are added to the database. This system design allows great flexibility, e.g. a standard set of object classes can already be present before the user teaches the robot specific objects.

# IV. ROBOT TASKS

# A. Call Hobbit

To facilitate easy calling of the robot to a specific place when user and robot are not in the same room, self-powered wireless call buttons are used as part of the AAL environment. Such stationary buttons can be placed e.g. near the bedside, in the kitchen or in the living room wherever the user frequently will be. When the user presses the call button, the robot will directly navigate to the known place so that it brings itself into a normal interaction distance and pose relative to the user.

# B. Introduction Phase - User Specific Setup

The default settings of Hobbit are a good starting point for most users. To allow for individual adaptation a so-called Initialization Script, which is run upon first introduction of the robot to the user and later on user request, guides the user through a set of questions. The user is asked for preferences on volume and speed as well as gender of the speech output voice; the user is invited to try out speech, gesture, and screen input and can give the robot an individual name it will answer to. The final prototype will also allow to configure the individual behavior settings, such as different robot personalities (more companion-like or more machine-like) and proxemics parameters. The selected values are directly demonstrated during the process to give the user immediate feedback.

## C. Clear Floor

Triggered by voice or touch screen, Hobbit is capable of cleaning the floor from objects laying around. The robot first detects the floor as the main horizontal plane and eliminates all points corresponding to the floor and clusters the remaining data to objects. The use of lower and upper limits for the size of point cloud clusters enables the elimination of objects that are too big (too heavy to be lifted by Hobbit) or too small (sometimes the floor is slightly rippled which leads to an insufficient ground floor elimination). The robot uses structural information about the domestic environment gathered during mapping phase to eliminate objects that are unlikely or impossible to grasp. As an example, if an object cluster is placed at the position of a wall, Hobbit does not try to grasp it since it is probably a segmented part of the wall. If Hobbit finds an object on the floor, it moves towards the object, grasps it and brings it to the user. If no graspable object was found, Hobbit changes its position and searches again on the floor until the floor is emptied or a stopping criterion is fulfilled (e.g.time spent on the task or the number of tries exceed predefined thresholds).

## D. Learn New Objects

To learn a new object, the robot has to see the object from multiple views and – for objects like a pack of aspirin which can be found in any pose – from upside-down. To achieve this, the robot uses a small turn-table (see Fig. 4(b)). The turntable is designed in such a way that the gripper can hold it in a defined pose. The user is asked to put the new object onto the turntable. The robot then slowly rotates its arm and captures views of the object while its turning. After a full rotation, the user is asked to put the object. The turntable rotates again and views are captured and stored. Now the user has the choice of teaching the robot another object or remove the current one. After finishing the learning, the new objects are immediately ready to be used in other tasks such as "bring object".

## E. Bring Object

Users can command Hobbit to search and bring a previously learnt object. For objects often needed by the user, Hobbit saves the typical object location, (e.g. the kitchen table). Hobbit first searches at this place, grasps the object, puts it on its tray and brings it to the user. To simplify scenarios during user trials, we used predefined arm positions for grasping. After the searched object was found, Hobbit places itself in a predefined position with respect to the object and executed a fixed arm movement to grasp the object.

## F. Fall Detection and Help Function

Fall detection of older adults is a major health risk and several systems have been proposed for the automatic early detection and prevention of such emergency cases [32], [33], [34]. To this end, fall prevention and detection is a crucial functionality that Hobbit is designed to support in order to help older adults to feel safe in their home, by identifying body fall/ instability or the user lying on the floor and handling emergency events appropriately.

A help function is constantly running by the system. In the first place, it is able to recognize abrupt motion of a detected and tracked human body that indicates instability



(a) Clear Floor

(b) Learn Object

(c) Fall Detection

Fig. 4. User trials: Hobbit brings an object from the floor to a user (left); Hobbit learns a mug; Hobbit detects a user fall and calls for help (right)

or an ongoing fall. Additional events can be captured as emergency alerts by the help function based on the GRI and ASR modules of the system (see II-E), such as a predefined emergency gesture or voice command, with which the older adult can ask the robot for help.

On a technical level, body fall detection is based on information related to 3D body tracking that relies on visual data acquired by the "head" camera of the robot and the 3D human observation functions (see III-B). A 3D bounding box of the detected human body is calculated for each frame and emergency detection is performed by analysing the length, velocity, and acceleration of each dimension of the calculated 3D bounding box in time. Our methodology bears some resemblance to the method in [35].

In case of a detected emergency, a subsequent part of the help function is triggered, namely the emergency handler, that enables the robot to safely approach the user's position, initiate an emergency dialogue to calm him and perform a phone call for help, if necessary.

## G. User Entertainment and Social Connectedness

Hobbit offers entertainment by allowing the user to listen to favorite music, watch videos, and play games. For the first prototype (only) some examples were integrated in the menu of the GUI. For the final prototype these will be extended adding also access to social media. Hobbit offers services for social communication including an internet phone used for the emergency scenario during the first empirical trials, but which can also be used to stay in touch with friends and relatives in general.

## V. FIRST USER STUDIES

First empirical user studies in a controlled laboratory setting with the Hobbit prototype were carried out in Austria, Greece, and Sweden, with a total of 49 primary users (PU), who were older adults from the age of 70 years with minor to severe age-related impairments, and their respective secondary users (i.e. relatives or close friends, SU). The objectives of these trials were:

- to test the usability of multimodal interaction with different groups of impairments;
- to test user's acceptance of Hobbit in a reciprocal condition, in which the robot proactively asked the user for help and offered to return the favor;
- to reflect on affordability issues;
- to collect data for improvements to be implemented into the next prototype.

The trials consisted of three parts: (A) the introduction phase, including a pre-questionnaire and briefing on how to use Hobbit and what it can do (B) the actual user study with the robot (six trial tasks) and (C) the debriefing phase with questionnaires for the PU and SU. Measures used were questionnaires, observation protocols, and video recordings of the trials. In the following we present a short overview on the main results, as the study details will be published elsewhere.

## A. Results

In general, PUs mostly enjoyed the trial situation and found the tasks easy to accomplish and the interaction with Hobbit understandable and traceable. Usability items in the questionnaires showed that improvements are still necessary for the initialization dialogue and wording of robot instructions in general. The robot was furthermore mostly perceived as being rather slow in the tasks. On the whole, the multimodal approach of Hobbit with interaction possibilities via voice, touch screen, and gestures was confirmed by the users. Voice and touch screen were the possibilities used most often. The learning task, however, will need to be adjusted and made more intuitive for older adults, including instructions from the robot and easier handling of the turntable for objects.

It could be validated that reciprocity, a key aspect of the Mutual Care paradigm, can be established even in a laboratory study and that this reciprocity was recognized as such by users. Furthermore, once PUs had experienced the "return of favor" option in the interaction with Hobbit, they did not want to miss it. Users interacting with Hobbit in the reciprocal condition perceived a higher usability (measured by the System Usability Scale [36]) than in the control condition.

According to the participants, most preferred feasible household functions which might increase the acceptance of a care robot for independent living are: picking up objects from the floor, fetching objects from a high shelf, and also following the user and transporting objects (i.e. questionnaire data). In terms of care aspects, it could be shown that a stand-up and a walking aid are highly interesting for older users. In terms of entertainment functions, memory training, music, audio books, and fitness instructions were most important for older users. Finally, with regards to affordability, answers from PUs and SUs in the debriefing questionnaires clearly indicated that participants were skeptical of buying such a robot, but could imagine renting it for some time if needed. From the results, it can be assumed that SUs are more likely to be a buying target group.

## VI. CONCLUSION

In this paper, we presented the Hobbit system, a care robot for older adults, which has the potential to promote aging in place and to postpone the need to move to a care facility. Hobbit is designed especially for fall detection and prevention (e.g. by picking up objects from the floor, patrolling through the apartment, and by employing reminder functionalities) and supports multimodal interaction paradigms for different impairment levels. Moreover, the development of Hobbit is based on a multidisciplinary approach and the sociological helper theory proposing a Mutual Care paradigm, assuming that the robot will be better accepted as assistive technology if the user and the robot care for each other.

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