3.1 Publishable summary

The HOBBIT project envisions a robotic product that will enable **older people to feel safe and stay longer in their homes** by using new 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), handling emergencies (calming dialogues, communication with relatives, etc.) as well as fall prevention measures (keeping floors clutter-free, transporting small items, searching and bringing objects, and reminders). Moreover, high usability, user acceptance as well as a reasonable level of affordability are required to achieve a sustainable success of the robot.

In order to achieve the goal of high **user acceptance**, the core element of the HOBBIT project is the concept of **Mutual Care**. Mutual Care is an interaction design framework for assistive robots to facilitate relationships with their users. Its main idea is the mutual understanding of each other's needs. Thereby, the robot learns the habits and preferences of the user to adapt its communication and behaviour. At the same time, the user adapts to the robot's intellectual and physical capabilities. In Mutual Care, the focus is on the conjoint adaptation and on strategies that follow the dynamics of real social relationships. Similar to a puppy, the Mutual Care robot and its owner adapt to each other when starting a new life together.

The theoretical framework for Mutual Care has been derived from a threefold basis. First, the sociological paradigm of “social roles” helps to understand the process of embedding robots within the social network of our target group. Second, the “helper theory” describes the social dynamics of mutual-aid groups. And third, the concept of “mental models” from cognitive psychology guides us to develop user-adaptive behaviour repertoires for HOBBIT. Based on this interdisciplinary framework Mutual Care is designed to work platform-independently and could be used with all other robot installations.

By mid-term of the project, a first version (PT1) of HOBBIT was realized and evaluated in a first round of user trials. The results are reported further below. Based on the received feedback, a new prototype PT2 was designed and is going to be evaluated in another series of trials in the final project period. As with PT1, also for PT2 the Human-Robot Interaction with HOBBIT will be evaluated in terms of usability, user acceptance, and affordability.

Overall the main evaluation goal is to explore the following main question: Do older adults experience HOBBIT and its Mutual Care aspects as a suitable mean to maintain independent living in their private household? In order to make this overall guiding research question operational and measurable in empirical research, we developed user trials in three countries and structured the findings into three main evaluation concepts: usability, user acceptance, and affordability.

The main work within the frame of WP1 of year two was organization and **completion of the scenario-based user trials with PT1**. These took place in Austria at AAF, in Greece at FORTH and in Sweden at ULUND. The trials with a total of 49 primary users (PU) and 35 secondary users (SU) followed a clear sequence of six tasks, and participants were divided into a Mutual Care and a non-Mutual Care condition, in order to examine and compare differences between the groups.

Results were gained from questionnaires, observation protocols and interviews with the participants during and after the trials. The results from all partners were encoded and analyzed by means of SPSS.

The most **important results** of the PT1 trials related to the three categories were:

Usability

- 49% of PUs found the robot easy to use and 46.9% felt rather confident in using PT1
- Voice commands and touch screen were liked best as operation mode by PUs
- In general, the usability of the MMUI has been confirmed by the PUs

Acceptance

- Users in the Mutual Care group perceived the support in the tasks significantly as more mutual than users in the control group (r=.357/p=.013).
- A pick up from floor-function was most important for PUs (52.2%), compared to picking up objects from the table or a high shelf.
- 77.6% of the PUs found a transporting functionality important.
- The implemented emergency dialogue was rated very acceptable by users in terms of length and speed.
- 65.8% of PUs fulfilling the inclusion criteria found it very important to use HOBBIT as an aid to stand up from the floor (after a fall).
- Overall, users with a mobility impairment found PT1 to be more helpful in their home than PUs without a mobility impairment (p=.001).
- In terms of higher acceptance through entertainment offers, memory training, music, audio books, and fitness instructions were most important for older users.
- Among SUs liking the design was significantly correlated with imagining to buy the robot for one's relative (r=.405/p=.020) and renting it (r=.361/p=039).

Affordability

- When asked directly, 63.2% of the PUs could rather not or not at all imagine buying such a robot (40.8% "not at all").
- Yet 77.6% of PUs could imagine to rent a HOBBIT (49% "very much"; 28.6% "rather").
- SUs also preferred a renting option (22.4% "very much"; 26.5% "rather").

Conclusively, the findings from PT1 trials pointed towards

- necessary changes in the dialogues of the robot,
- changes in speed of the robot,
- design of HOBBIT,
- a possible renting-business model for a future product,
- and extension of speech commands.

It was furthermore analyzed which functionalities are more important to users than others, as an indicator for PT2 scenarios. While pick up from floor obtained high priority, functions such as a walker or grasping from a table are ranked medium resp. low. Consequently, the project will aim to provide the high priority functions first.

The **Mutual Care hypotheses** were tested and could be confirmed, underlining the basic dynamics of Mutual Care to be working. In the task, where the robot is asked to bring the object and the user had to help, users perceived this reciprocity, the basic element of Mutual Care. And the effect had endurance. The Mutual Care robot was perceived as easier to use, users perceived that less training was needed before get going with the robot, and users did not want to miss the "return of favour" feature.

Based on these findings, the **PT2 user trials** at the end of the project will study which of the functions and modes of interaction made available through Hobbit are mostly used and thus experienced as helpful, and, in particular, if self-efficacy and perceived safety (e.g. in terms of fear of falling) can be increased. Furthermore, PT2 user trials will be used to assess if the Mutual Care concept is able to improve user acceptance.

All thoseaspects will be investigated in PT2 using

1. Interviews & Questionnaires: before, two times during the user trial (on day 11 and day 21), and about one week after the trial for primary and secondary users.
2. Cultural Probing: the user observes and judges the safety issue.
3. Logging Data: recording interaction events, and their progressions.

Results of PT1 were the basis for developing the **scenarios for PT2**. The planning and designing of PT2 trials has been finished with the creation of scripts that encode robot behaviour. Mutual Care parameters are modelled based on social role, which is tool-like or like a companion. Becoming more social is implemented by increasing the presence of HOBBIT close to the user, increasing the number of interactions with the user and making dialogues more amicable. In this way we want to find out what preferences users have to obtain high acceptance.

The older **person and HOBBIT communicate and interact in several different ways**, using speech, text, gestures and a touchscreen depending on the preferences of the individual user. Systems for Automatic Speech Recognition and Text-To-Speech that support necessary languages (English, German, Greek and Swedish) have been implemented as speech is an important way of communication according to the results from the workshops with users. The UI was used and evaluated in the PT1 trials. During the trials work started on the advanced user interface for PT2 and improvements on ASR performance under varying distant speech conditions. Observations from trials were used to guide the laboratory testing of microphones and speech recognition engines, comparison with reports on state of the art and contacts to related projects in order to find the optimum balance for PT2. The UI was extended with more entertainment related functions, the physical activity and other new interaction for PT2.

A new appearance **design** has been developed **for PT2** based on the results from the PT1 user trials. The PT2 design has more ergonomic positions of the touchscreen and the tray, a solution for improved usability for the “learn object” task, improved cleaning possibilities and a slightly reduced height. The robot has been manufactured and assembled and is now ready for the final user trials.

A concept for a **behaviour framework based on the Mutual Care idea** has been developed and is implemented in PT2. It encapsulates the underlying behaviour model for easy use by the execution modules. The behaviour is based on a set of parameters that can be changed directly by the user or by adaptation to evolving needs.
The render the behaviour framework robust to novel or unexpected situations, we designed the system to cope with variations at two levels. The function level creates the main robot functions such as the MMUI and navigation to be in themselves redundant and able to cope with unforeseen situations in a pragmatic way. For example, the redundancy of the MMUI is exploited if one input modality fails. The second level is the system level. Exploiting the state-based approach we introduced a four-layer approach to catch faults created at the hardware layer, the ROS node layer, the state-machine behavior level, and eventually at the human assistive layer. The top layer reverts to the Mutual care paradigm and activates the user to bring the robot back to a known state, e.g., pressing the call button again or helping to move the robot into the docking station.

HOBBIT provides **connections to AAL (Ambient Assisted Living)** solutions. A call button, based on wireless components producing energy from pressing the button, is used to call the robot to a specified location. Call buttons can be freely placed within the apartment of the user. For PT2 an advanced AAL interface has been developed which allows the integration of further sensors and actuators in the user’s home environment such as emergency sensors in the bathroom and toilet.

A rich set of **HOBBIT visual competences** was realized, integrated to the PT2 platform and evaluated during laboratory and pilot tests with elderly users of Hobbit. Regarding the tasks for **vision-based human body detection, localization and tracking** (T5.1, T5.2), a new modular architecture is introduced for PT2 in order to include the novel methodologies developed for efficient 3D detection and tracking of upper and full body human, including hands and fingers. The new methods perform considerably faster, provide a more accurate estimation of a skeletal model of the human body in various configurations and are able to track complex and rapid movements of the visible body parts, without requiring initialization. Various system functions and scenarios rely on relevant information that is extracted from these modules, i.e. locate the user in the scene, approach the user, emergency detection, gesture recognition, etc.

The final refinement and integration of the **fitness** application was also performed based on our novel methodology for 3D upper body tracking developed for PT2. Overall, the application aspires to define an adaptable application provided by the HOBBIT MMUI serving as a vision-based physical trainer for the user. A set of four exercises were included and tested in lab and pilot trials in view of the for the PT2 trials.

The **gesture/posture and activity recognition** functionality (Tasks 5.3 and 5.4) was further improved towards intuitiveness and performance of the human-robot gestural interface. A novel method was developed to recognize new physical movements based on arms, hands and fingers which are more natural, intuitive and easier to be performed by the elderly. In total, seven gestures are now supported based on the movements of the arms and/or the hands of the user who may be either standing or sitting in front of HOBBIT. The gestural vocabulary corresponds to the following robot commands: Yes, No, Help, Reward and Stop/Cancel an ongoing task. Most importantly, as suggested by the reviewers, a new gesture was introduced implementing the **"Come Closer" gesture** that instructs the robot to further approach a sitting user and thus facilitate the user to reach the tablet on-board screen. Additionally, a new method was developed to perceptually support the **"user follow" behaviour**.

A novel methodology was also developed for the problem of **simultaneous action segmentation and recognition of daily actions** of the user. To assess the effectiveness of the proposed method, a series of experiments were conducted based on datasets that are widely adopted by the research community, but also during lab trials and pilot tests in homes of elderly.

A new methodology for **emergency detection of a fallen user** was developed**.** The method considers the case of a user lying on the floor while the robot is navigating. The new method acquires depth and thermal visual data based on the sensors mounted on the head of HOBBIT s well as the bottom camera of the of PT2 platform. A single measurement is provided by the thermal sensor, aligned with the central depth pixel of the head camera indicating the temperature of that single point on the targeted scene frame. This cue is combined with the efficient depth-based detection and segmentation of an elongated blob on the floor from both head and bottom cameras and classifying it as (a) a user lying on the floor, (b) an obstacle and (c) no object. The final set of vision-based emergency detection methods include (a) the detection of a falling user while the body of the user is observable prior and during the fall, (b) the detection of a fallen user that is lying on the floor while the robot is navigating and (c) the recognition of the emergency (help) gesture the user can intentionally perform through the PT2 MMUI (GRI) to signify an emergency situation.

Regarding **Navigation**, HOBBIT replaces the commonly used laser sensors with two RGB-D sensors. One sensor is mounted just above the floor and looks forward. It is used for **mapping and localisation**. Tests showed that the robot can navigate indoor environments such as homes given a minimum distance for the robot to pass. The map is built first and with a simple tool we annotate rooms. Next all places of interest to the user can be programmed by leading the robot to these places. Call buttons (AAL component) can be used at different locations to call the robot to a pre-defined location. Places are given names and are automatically associated to rooms. In this way we obtain a hierarchical room – place structure that is good for larger apartments and cognitively similar to how humans refer to places. Localisation has been tested and it turned out to be accurately enough to place the robot within a few centimetres of the desired place. To further improve localisation and to reduce the likelihood that the robot does stop or does not arrive at its target, we devised a method of localisation monitoring. Based on the localisation likelihood and a map match we regularly check if the robot location is good. If not, the present robot navigation goal is interrupted, a rotation to increase the field of view of the RGBD sensor is initiated, and it is expected localisation certainty improves given more data from the environment. Once confidence is gained, the interrupted goal is reissued and navigation proceeds.

The second RGB-D sensor is mounted on the head and can look down on front of the robot. It is used to **detect drivable floor and obstacles**. Navigation will then adapt its path as long as there is sufficient space. In case of a way blocked, the robot will notify the user and ask to remove the obstacle. Navigation plans paths between any stored places. Mapping and navigation have been tested with several settings and also introducing narrow passages. The methods have been ported to PT2. With this sensor configuration it is possible to replace costly laser scanners while additionally scan over all height ranges relevant for the robot and it allows the robot to see on tables, which is necessary for object search.

Regarding **object detection**, HOBBIT will be the first robot to provide the **functionality to learn objects** dear to the user and to then search for the objects. We provide a learning method based on texture and shape of the object which allows to model objects that can be put on the turntable in the robots hand. While dimensions are limited to be neither too small not too large, it is the first time such a functionality is put forward and made available to the user directly. Additionally, it will be the first time with HOBBIT that a robot will search for a learned object in the user's apartment. The methods have been tested on a set of objects that have been named by users, such as key chain, wallet, mobile phone, glass case, handbag, cup, mug, bottle and similar objects.
To **search for the learned objects** we introduce an object detection pipeline that combines the strength of three different methods to detect objects. It uses a correspondence grouping and a refinement step to verify object locations and delivers accurate pose (position and orientation) of the detected object. Object viewings are additionally used to guide the search for an object, e.g., by starting first at the location where it has been seen recently.

An important functionality of HOBBIT is to **grasp object from the floor** - a primary need **to prevent** potential **falls**. Hence, we improved the method for grasp point detection (Height Accumulated Features - HAF) and extended it to cope with certain situations where objects were placed on top of bigger objects (like boxes) and near to the objects boarder of these bigger objects. These improvements were published at ICRA 2013. Furthermore, the results demonstrate the capability of the approach to grasp objects in cluttered environments (e.g. in a pile of objects). To make this work on HOBBIT we obtain a calibration between the head camera and the arm and gripper based on markers and improved the trajectory planning. We ported this method onto the new arm for PT2, which has 6DOF.

HOBBIT also investigated walk and rise functions, but these have not been integrated in PT2.. Concepts for walking assistance have been drafted in a one-handed and a two-handed solution. However, users prefer to see rise functions implemented. A **rise-from-chair** functionality has been developed and was tested in lab trials. It is based on a concept where the user can get support from HOBBIT without compromising HOBBIT's stability by triggering the user to lean forward and support one knee while they are making a pushing down force instead of a pulling force. We have made prototypes and tested them with two old users. Similarly, a **rise-from-floor** concept has been developed, which is based on the idea that HOBBIT could bring an object which enables older adults to safely get up from the floor on their own. We developed a conceptual prototype for this object together with physiotherapists. First tests indicate that the concept is well accepted by users, however to conduct tests in home settings medical clearance is required which cannot be achieved within the project. It remains an idea to be pursued in future work.

The project kept its homepage alive. **Project website address:** http://hobbit-project.eu/
Details have been reported in D9.1, which is open for download. The Web-page complies with the World Wide Web Consortium's Web Content Accessibility Guidelines, which makes it accessible according to W3C-WAI Web Content Accessibility Guidelines (WCAG 2.0).

The Web-page hosts material for download, for example a project folder, a short presentation, and many of the publications have been made available for direct download. The project is proud to receive excellent coverage in the public. News items continue to be produced and the web-page is kept up to date.

The **final results** of the HOBBIT project address several socio-economic and wider societal impacts. Acceptance for robots in the homes of elderly will increase through the mutual care concept. This will increase, or speed up the increase, of service robots caring for elderly at home. Both the HOBBIT robot, as well as other robots will benefit from the proven increased acceptance of the mutual care concept (PT1 trials). As this concept includes both hardware and software components, at a minimum the software components can be incorporated in any future robot. The increase in acceptance will increase the number of robots active in caring for the elderly, which is still a major societal and socio-economic challenge.

The results of PT1 user trials indicate that the acceptance for robots before and after a trial with the HOBBIT robot significantly increases. It confirmed that the acceptance of robotic helpers can be significantly increased though mutual care.

The cost (time) of informal care is currently burdened in large by females family members, giving informal care to relatives. HOBBIT will decrease the need for time spent by women for care, thereby increasing their available time to peruse either a career or to be used for recreation, thereby increasing the Quality of Life (QoL) not only of the elderly, but also of their informal caregivers.

Furthermore, the focus of HOBBIT on fall prevention can significantly increase the QoL for elderly people living independently. The increased time they can stay in their own home, along with the pains associated with a fracture at a higher age are significant improvements to the QoL of elderly. This has both a socio economic dimension, as elderly patients who suffer from a fracture have high treatment costs, as well as a **societal implication**, as it enables an elderly who are not as mobile to continue to interact with society, through a device tailored to their specific needs.

The final result will be a robot that improves the quality of live and prolong independent living of senior citizens through the fall prevention, fall detection and auxiliary functions of the mutual care robot. The expected **socio-economic impact** is to present a prototype mutual care robot (HOBBIT) as unique selling point for European industry including the conceptual approach of Mutual Care to increase user acceptance through human-machine bonding.