Development and Evaluation of Assistive Terminals for the Improvement of Functional Performance of the Elderly in a Variety of Life Centers

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Abstract

In this paper the authors present the equipping of a 1:1 scaled AAL laboratory apartment with prefabricated compact "terminals" that concentrate on assistive technology. The development has been conducted within the Project LISA HABITEC, which is funded by the City of Bozen, Italy. Within this project new possibilities have been investigated, to enable an independent and self-sufficient life for elderly.

Therefore, terminals for the different life centers of an apartment (bed, bath, living room, entrance area), have been developed, where service and support modules can be easily attached, e.g. by plug-and-play. Thereby, the proposed AAL solution is highly customizable towards the user's needs, health situation, and financial resources. The service modules contain functions such as unobtrusive detection of health data (e.g. ECG, temperature etc.), active support systems like stand up support (e.g. by decent integrated handles), and service robotics integrated into the furniture.

This paper describes the outcomes of the second development and evaluation cycle in the project (formative, pretesting) in which through standardized qualitative test in a laboratory test apartment, with 9 test subjects (N = 9), terminals of four different live centers, have beenevaluated (technology verification, workflows, usability, etc.), in order to provide input for improvement, automation and extension of the functionality of each terminal in the third (final) development testing cycle.

Keywords

Active Assisted Living, Smart Home, Unobtrusive ICT Implementation, Modular Subsystems, Sensor Application

1. Introduction

AAL refers to Active Assisted Living (also known as Ambient Assisted Living) [1], which aims at enabling the elderly and fragile to stay independent and self-sufficient through technological support. The need to deploy such solutions increased in the last years in nearly all industrial nations [2, 3], and until 2050 a multitude of countries are expected to become highly-aged societies. The demographic change has a strong impact on industrialized nations such as Germany, Japan, Korea, and Italy, and in the end even China, and leads to an increasing number of health issues, functional decline [4], and finally increased health care costs [5].

Statistics predict that due to this, pensions will not be enough in future, to sustain financial independence [6]. Additionally, it is expected that relatives, e.g. children of the retired, will be busy with career issues and own children, and therefore not able to take care of elderly [7]. Furthermore, the assistance of elderly to live independently has a positive impact on the availability of human capital [7]. Additionally, the number of educated caregivers is expected to fall drastically [2]. Technology, which enables elderly to stay independent, and mitigates functional decline, the impact of frailty and other diseases in high age by selective, human-centered assistance, is increasingly be considered as the future of care and thus addressed by a multitude of initiatives such as the H2020 tracks on Personalized Health Care, the Ambient Assisted Living JP, and the EIP on Active and Healthy Ageing.

More and more projects aim to implement monitoring and assistive technologies into wearables (e.g. smartwatches, smartphones etc.), or into the ambient environment [8]. Health data are measured, analyzed, and monitored by devices or equipment, in order to provide the user feedback about the individual health status (e.g. pulse measured by the Fitbit Flex [9] etc.) and prospect.

However, mainly younger people tend to actively use this technology, whereas the use of this technology in rehabilitation, and elderly care is relatively new [10]. Considering the aspects of the limited technical affinity of elderly, and the mentioned financial constraints, it is important that new, cost effective AAL technology will be developed, which enables elderly to stay independent. Existing prevention and health tracking solutions, need to be taken further into an integrated built environment, in order to enable an unobtrusive implementation into the living or home environment.

In the outlined context, LISA HABITEC (see Figure 1) focuses on pre-embedding assistive functions in a modular element (that allows for mass-manufacturing and fast and cost-effective installation) as a kind of furniture or cabinet (= terminal module), which can be later installed in the room without requiring refurbishment of the existing interior.

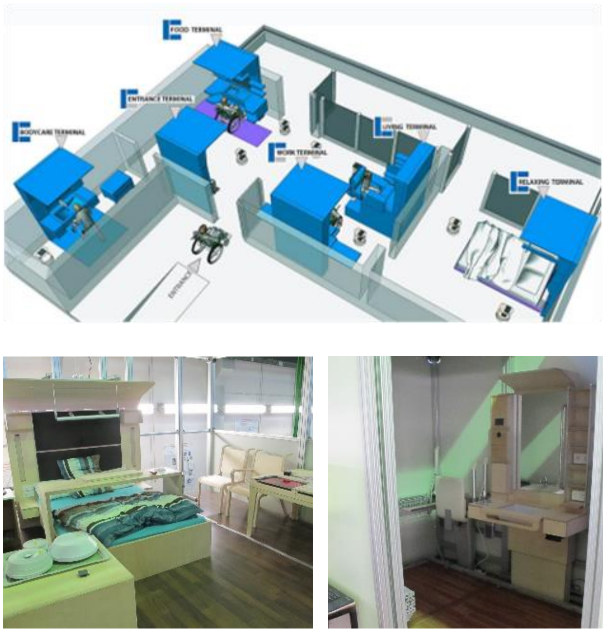

Figure 1. LISA HABITEC focuses on pre-embedding assistive functions in a modular element as a kind of furniture or cabinet (= terminal module), which can be later installed in the room without requiring refurbishment of the existing interior. Top: overall concept; bottom left: bed terminal; bottom right: bathroom terminal.

Because of the concentration of the assistive functions in a single terminal, a compact element is created, which can efficiently be produced and installed in the apartment.

Whereas LISA, focused on the development of a terminal [11] and the general approach [12], in LISA HABITEC networked terminals for all key Life Centers (body care, food, working, living, relaxing, and entrance area) have been developed, tested and evaluated.

2. Research Method

LISA HABITECH develops the terminals for four Life-Centers in three subsequent iterative development cycles. In the first development cycle based on interviews and discussion with the defined user group in three focus groups with each 10 exemplary users (N=30), discussions and reviews with care providers and care home operators, as well as a systematic literature review, the system requirements and functions have been identified, and the initial design of the terminals was developed. In the second development cycle, the four Life-Centre terminals have been prototyped as 1:1 scale mock-ups with the most important functionality (mechanical support systems, sensors, basic functions such as lighting systems, etc.) and tested in an AAL-test flat resembling in the laboratory in a comprehensive care scenario. In this stage in the controlled laboratory environment usability test with 9 test subjects (formative pre-testing) was conducted to provide feedback and usability requirements, which can be used to improve and expand the integrated functionality. In the third development cycle, the improved terminals will be tested (summative final testing, and overall outcome summary) over a duration of several days in a (real world) operational environment of an assisted care facility stating the first potential operator. In all three development cycles, in order to minimize bias, the user feedback and testing was organized and conducted by an objective entity (BIS), which is not involved in the actual development process.

This paper focusses on reporting outcomes of development cycle two. Outcomes of the other cycles and the overall summary will be published in separate papers.

3. AAL Terminals and the Modular Functions

The in LISA HABITEC proposed solution aims to add modular systems by plug-and-play to an existing terminal, as described in [11]. The existing terminals provide all necessary supplies (e.g. electricity, parts of the building technology), which the corresponding modules need. After the installation of the terminal, the service modules can be easily attached using plug-and-play connectors to upgrade and personize the assistive capability even over time.

In [11] the functionality was focused mainly on the entrance area. However, in LISA HABITEC, the approach has been further developed in order to install terminals for the other life centers (mainly living / kitchen room, bedroom, and bathroom). Also new features have been added and prototypically implemented, in order to investigate how to improve the so far developed assistive functions.

In order to integrate individual terminals and overall system, the different modules embedded in and distributed over various Life-Center-based terminals communicate

with each other wirelessly using an XBee network [13]. The main advantage of the XBee antennas (XBee Pro Series 2B [14]) are the high range and the small size of the antenna. For the communication and data transmission, the ZigBee protocol is used (e.g. as described in [13]).
In the following each terminal is shortly described in its functions, which have been implemented into a laboratory test apartment, which is depicted in Figure 1.

3.1 Living Room Terminal

The terminals developed in LISA HABITEC do not necessarily have to be installed on the wall, but also furniture elements such as table and chairs serve as terminals and can incorporate the assistive functionality. As elderly, especially in Europe, do not trust robots (compared to elderly of Japan), the mobile platform Lynx Adept has been integrated and hidden into a table, which increased the user acceptance of the robotic solution. To control the robot, a BeagleBone Black [15], which is connected with a touch LCD screen, has been used as remote controller. The remote controller runs an application, programmed in C++ with QT5, which calls over a SSH connection, to the Ubuntu 12.04 PC unit on the mobile robot, the appropriate programs for movements. For communication the Wi-Fi network is utilized, which is separated from the XBee network, which is mainly used for vital measurements data exchange. Thereby, the different data streams cannot interfere with each other.
The initial scenario envisioned, and tested, for this integrated mobile platform, is to assist with serving plates, dishes and food, which are compatible with an induction heater, unobtrusively implemented into the living room terminal (see Figure 2). The mobile table is considered as an add-on module.

Figure 2. The mobile platform hidden in a (right) table, which can autonomous drive, controlled by a small touchscreen, which is placed on the table.

In a chair, also an add-on module of the living room terminal, which contains a capacitive ECG System, has been implemented, in order to measures the ECG of the user by placing the hands on the armrest. By using the capacitive sensors of Plessy [16, 17], no glue or other liquids are necessary at the electrodes. Thereby this approach allows to use the electrodes as dry electrodes, which do not disturb the daily activities of the user, and therefore are much more comfortable.
Furthermore, this approach has the potential to measure through cloths, as long as the layers are not too thick and the application is properly shielded [18]. However, questionnaires, filled by the elderly in the pre-study presented in this paper, showed that they prefer to have e.g. a specific posture, to trigger a measurement, in order to keep the control over the captured data. Therefore, the capacitive electrodes have been implemented in the armrest as depicted in Figure 3.

Figure 3. The capacitive Electrodes modular attached at the sides of the arm rests of a test chair.

3.2 Entrance terminal

As depicted in Figure 4, the original design form the first LISA project has been improved, so that less space for this terminal is now consumed.

Figure 4. The entrance module; Left the result of the pre-project described in [11]; Right, the designed improved version, with novel assistive functions.

The prototype of the first LISA project entrance terminal (Figure 4, left) contains functionality such as wireless data transmission to a health server for easy access of blood pressure, pulse, blood sugar, and body scales measurements (by Wi-Fi). Also a reminding function, using RFID-technology was implemented. This approach enabled a decent way to alert the user when e.g. the keys were forgotten [11]. In the smart mirror a weather app informed the user about the current temperature, in order to give support in finding the appropriate clothing.
In the entrance terminal developed in LISA HABITEC (Figure 4, right) the main focus was laid on assistance in the set of activities related to sitting, dressing, putting on shoes, and standing up. For this purpose, a stand up support “Uplift Premium Power Lifting Seats” has been mounted in the seat place from the company Uplift Technologies Inc. [19].
Additionally, a belt lifting system, which is implemented as a mock-up, allows to drag the user into the standing position.
Next to the already implemented modern version of a shoehorn, a movable plate, can lift up (as depicted in Figure 5), in order to support the user in putting on the shoe. The special shoe shelf, mounted on the left, allow an easy and ergonomic access to the shoes, because of the rotatory wheel concept of the shoe shelf, the shoe is always in reach of the user (see Figure 5). Although, in this first development cycle the functions are not actuated, the aim is to go in the next development cycle (using the user feedback presented in this paper) towards selective automation of the described activity set.

Figure 5. Left the moveable plate as support to get into the shoe; Right the ergonomically shoe shelf

3.3 Bed terminal

The main purpose of this specific terminal is to offer selective support in getting in and out of the bed, as well as to mitigate the functional inability of the user. Normal solutions in hospital beds mount e.g. a trapeze bar over the user. This application is very helpful but in the home environment stigmatizing and unpractical. Therefore, this handle in the bed is implemented with a strong motor, which can drive the handle up and down using a remote controller (see Figure 6).
Furthermore, the bed terminal addresses the problem of getting out of, and standing up from, the bed. For this purpose, handles unobtrusively implemented into the bed terminal allow the user an easier way out of the bed (see Figure 6). The table system on the bed is mounted on a sliding rail, which need only minor efforts to be moved. The integrated folded table (depicted in Figure 6), allows to eat, to read books, and/or to work with a laptop in the bed. The aim is also to automate this functions in a next step based on the user feedback.

Figure 6. Left top, the unobtrusive implemented handles; Right top, the remote controlled handle; Left bottom, the integrated table on a sliding rail, which is unfolded in the figure at the right bottom.

3.4 Bathroom terminal

The bathroom terminal (see Figure 7) incorporates an actuated and height adjustable sink. The height adjustment allows also to store specific height positions, so that in a family with up to four members, each family member can call the preferred height adjustment. In addition, a cabinet lifting system is realized as mock-up (see Figure 7). This small lift needs only very small actuators, in order to move objects from the top of the cabinet down to the user. Here a mechanism to shift the item on the lift plate is currently under development.

Figure 7. The bath terminal module; Left, testing the fever detection; Right, testing the mock-up cabinet lift system.

Next to an unobtrusive fall detection system, which is implemented at the ground as baseboard of the bath environment, is the fever measurement module. The module is unobtrusive implemented next to the mirror, consisting out of a thermal camera, which is connected to a BeagleBone Black, which analyzes the potential presents of a human face. If the system detects a face, the

thermal image will perform a fever analyzation at the center of the forehead. By using a standard derivation, wrong measurements (e.g. samples captured at the hairs) can be automatically removed, which increase the reliability of the systems [20].
The display, implemented in the bath terminal is optional, for someone who want to see the result immediately. Once the camera is running, the attached BeagleBone Black, which is analyzing the temperature, is transmitting the final result of the fever measurement using the XBee network, together e.g. with the information of the fall detector on the ground, to the destiny server, where the values/data are stored.

3.5 The implemented functions of the laboratory apartment – an overview

Considering the unobtrusive implementation, connected by the Wi-Fi and XBee networks, the overall test apartment offers the in Table 1 listed assistive services for elderly and fragile. The implemented services are realized as mock-up and partly functional, or as prototype and fully functional. In the context of the fully functional applications, like the temperature measurement or the ECG application, the XBee network connects the devices with each other.

Table 1. Implemented functions in the different live centers of the laboratory apartment, distinguished in functional prototype and partly functional mock-up.

Level	Live center	Functions
Functional Prototype	Bedroom	Remote controlled trapeze bar
	Living room	Dry electrode ECG in the arm rest of a chair
		Remote controlled mobile service robot
	Bathroom	Unobtrusive fever detection
		Unobtrusive fall detection
	Entrance area, (Prototype 1)	Reminding function us RFID Technology
		Remote data transmission of scale, blood pressure meter, blood sugar meter, including health platform
	Entrance area (Prototype 2)	Stand up support implemented in the seat
Mock-Up	Bedroom	Unobtrusive side handles for standing up support
		Foldable table on a sliding rail
	Living room	Inductive cooking/warming plate
	Bathroom	Cabinet lift system
	Entrance area	Rotational shoe shelf combined with height adjustable shoe plate
		Belt lift system

The data transfer, which is related to the health monitoring is separated from the Wi-Fi Network, which is mainly used for service functions, like remote controlling the mobile robotic platform.

4. Laboratory Test of the Proposed Laboratory Apartment

The proposed terminals, including the implemented mock-ups and prototypes, have been tested by 9 invited elderlies, with the support of the BIS. The average age of the elderly was 74,1 years, and was ranged from 63 up to 92 years. As the functionality spectrum is quite large, as it can be seen by Tab. 1, the laboratory test was composed of 6 subsequent stages. In the first stage the people filled in some questionnaires provided by BIS, which obtained insights into motivational aspects and the technical affinity of the study subjects. The technical affinity of the study subjects is depicted in Figure 8.

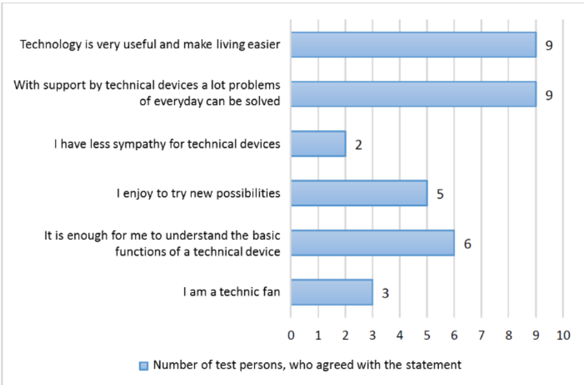

Figure 8. Documented technical acceptance of the test persons.

Next, the test apartment was demonstrated to the test person. Then the test persons had to use each terminal according to the provided demonstration, and after completing usage activities in a life center a break has been done, where the test person had to fill out the questionnaires, which helped to obtain user acceptance and functionality levels with regard to the tested terminals and functions.
In order to make the use case understandable for the users, a user scenario was developed, which explains how the different terminals integrates to one single AAL laboratory apartment.
In this scenario the test person had to imagine that they feel uncomfortable after awaking from sleep in the bed (e.g. caused by a weak blood circulation). The functions implemented in the bed terminal allows the user to get out of the bed and go to the bath, in order to prepare for the day. There the fever measurement calms down the user, as no fever has been detected, and the dizziness is probably only caused by a weather change.
At the table, the mobile platform brings the food, and the implemented inductive stove keeps the food warm until the user is ready to eat the food. To be sure that no serious health issue exists, the user perform an ECG health check,

which relieves the user by any serious worries. Finally, with the implemented functions of the shoe dressing support, the user can quickly prepare for leaving the apartment. The dizziness feeling is not an obstacle in standing up, since there are several supporting options provided in the entrance terminal.
To pass all 4 test stations (terminals: bed, bath, table, and entrance terminal) an hour per test person was scheduled. At each station the test person had 10 minutes to test the modules and the implemented prototypes and mock-ups, before the test person filled out the questionnaire (for approximately 5 – 10 minutes). Once stages 1 – 5 have been completed, the test person had a guided interview with the experts of the BIS for ~ 15 – 20 minutes.
The results of the questionnaires showed that the fall detection, as well as the unobtrusive stand up support systems in the bed terminal, are the favorite functions of the elderly (see Figure 9).

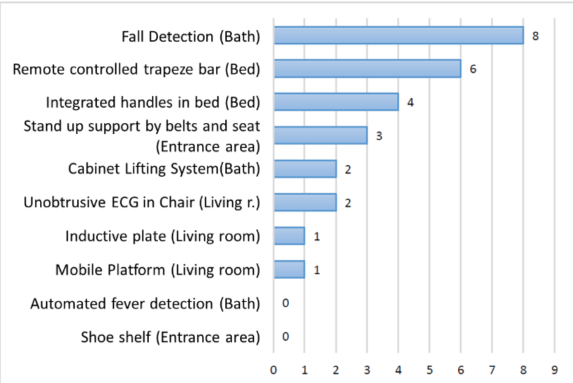

Figure 9. The most favorited functions by the test persons.

Most of the test persons can imagine to implement parts of the tested functions into their private apartments. Also to move into a care home, which is equipped with the proposed technologies, was preferred (compared to a normal care home) by the test persons. The test persons also suggested to improve the automation (e.g. work flows, + data interpretation, etc.) as it might be, for example, too difficult for the end-user to interpret the measurement values correctly, without medical knowledge, or operate the proposed complex mechanical systems.
In addition, the test subjects suggests that the overall modular approach is taken further so that the users can combine and individualize the upper body raising support, which was considered as useful but not yet technologically and ergonomically mature. The stand up support solution and the table functions where considered as the most useful and important functions and further automation of these functions was suggested. The usability of the fever detection system was considered as low, whereas the fall detection system was assigned to good usability and high importance. In the context of the kitchen terminal, the mobile robotic table and the in the table integrated food warming functionality were assigned to good usability and importance. The usability of the vital signs measurement function integrated into the chair warrants further improvement in terms of reliability and the user interface. In the entrance terminal the set of functionalities related to standing up, sitting and putting on shoes was considered as useful but needing further improvement in terms of ergonomic aspects, workflow and automation.

Conclusion

In this paper, the authors proposed the implementation of several services and support functions for elderly and fragile. By further developing the terminal approach, which has been pre-investigated in [5], a 1:1 scaled test apartment of 32 m² size has been realized. The terminals are connected wireless by XBee for data exchange, and can use Wi-Fi for server applications, such as internet services like the weather function, or remote controlling mobile platforms.
Vital data, like the body temperature, ECG, but also a detected fall of a person are unobtrusively implemented into terminals, in order to avoid stigmatizing the user. The combination of various support technologies enables the user to be more independent. By the modular approach, the terminals can be personalized, depending on the financial situation, as well as the actual user needs.
The test apartment allowed to test in an early development stage of the terminal approach, the usability. Thereby the end user feedback is very early considered in the implementation. For this purpose, a laboratory test has been done with nine test subjects (N = 9) with an average age of 74,1 years. The test ended the second development and evaluation cycle in the LISA HABITECH project in which through standardized qualitative test in a laboratory test apartment, terminals of four different live centers have been evaluated in dimension such as technology verification, workflows, usability, etc., to provide feedback and observations that can be translated into inputs for the improvement, automation and extension of the functionality of each terminal in the next final development-testing cycle.

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