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Assistive robotic micro-rooms for independent living

Thomas Linner, Jörg Güttler, Thomas Bock, Christos Georgoulas *

Chair of Building Realization and Robotics, Technical University, Munich, Germany

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ABSTRACT

The demographic change situation in Germany, as well as in other leading industrial nations, leads to an overload of the family and institutionalized nursing care system structure. For this reason, novel solutions must be developed, in order to guarantee fully independent living of the elderly people, and an efficient assistance or nursing, in diverse living environments. The research project LISA has investigated the possibilities to embed mechatronic, assistive functions and services into compact wall “terminal” elements thereby enabling autonomous and independent living upon performing Activities of Daily Living (ADLs) by means of generated structured environments and robotic micro-rooms (RmRs). In this article, a classification of the approach in the broader context of research, as well as a statement of methodical and structured multi-phase development are described. The conceptual and development phases and the technical details using selected assistive functions of the entire system are presented. The article explains the methodical approach throughout the four phases of development and focuses on essential field trials with collected user feedback.

1. Introduction

Due to natural aging processes, in a biological/medical and cognitive sense, it is more difficult for people to master ADLs on their own [1–4]. If someone loses the ability to self-maintain at home, care in nursing homes or by a family member is usually necessary. ADLs, refer to basic tasks of everyday life, such as eating, bathing, dressing, toileting, and transferring. When people are unable to perform these, they require assistance in order to cope, either from other human beings, or assistive devices, or both. Although persons of all ages may have problems performing the ADLs, prevalence rates are much higher for the elderly than for the nonelderly. Within the elderly population, ADL prevalence rates rise steeply with advancing age and are especially high for persons aged 85 and over [3]. However, the demographic change problem in Germany, but also present in other leading industrial nations such as Japan, Korea and China, leads to an overload for the family members and institutionalized nursing systems. At the same time, a reduction in financing for older people is observed, as well as in the economic productivity within Germany, as there are fewer employed productive individuals [5]. Furthermore, many elderly people live apart from their family (e.g. their children), usually for employment location related reasons. This is even more prevalent for elderly people living in rural areas. Various research projects are being carried out by the Chair for Building Realization and Robotics that deals with how to enable independent and dignified living for elderly people, by intelligent environment equipment which can be considered as novel approaches in the field of gerontechnology. Thus, for example in the research projects PASSAge [6] and GEWOS [7], the integration of assistive functions in mobility products and home furniture under complex, interdisciplinary research collaborations was investigated. In the research project LISA (Living Independently in South Tyrol Alto Adige), which is the focus of this article, the authors examined the possibility to integrate assistive functions in walls or wall components to generate structured environments, so-called RmRs, that can also be retrofitted into older buildings without requiring high costs, to enable independent and self-oriented living of elderly people. The economic potential of such a solution has been classified as very large by participating industrial partners concerning the middle- and long-term aspects, as it was noted that all currently emerging industrial global nations are experiencing the process of demographic change [8], while the trend towards individualization and self-centeredness in society progresses and therefore classic family assistance structures are being dismantled [9].

In Section 1, an outline of the research need and research question followed by a classification of the approach in the broader context of research and the methodical and structured approach in the developing phases is made. In Section 2, the concept of the overall system is described. In Section 3, the technical details of the selected assistive functions are presented. Section 4 describes the methodological approach in the four phases of development and is focused on gathering and integrating test-user feedback in several development cycles. Section 5 depicts how the system was designed in order to develop a higher-level product-service system. In Section 6, the most important milestones and research results regarding the research project LISA are summarized. Finally, Section 7 shows how obtained research results can be exploited and provides an outlook on the already initiated related

* Corresponding author. Tel.: + 49 89 289 28650; fax: +49 89 289 22163.
E-mail address: christos.georgoulas@br2.ar.tum.de (C. Georgoulas).

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research, which focuses on scaling the system in terms of assistive functions.

1.1. Related work and research question

Some researchers have already proposed approaches to integrating mechatronics and robotic technologies into environments and to create robotized environments. robotic rooms [10], Wabot House [11] or Robot Town [12] have investigated the important basic approaches and foundations in this field of research. Robotic environments differ in regard to complexity, quality and multi-dimensionality of possible assistive functions relative to the classic “smart home” approach (the precise definition of the “smart home”-approach of assistive and robotic environments is discussed in detail in [13]). In [14], environments that are provided with a certain degree of intelligence complexity, autonomy and a plurality of distributed and embedded sensors or microprocessors are analyzed and referred to as “immobile robots”. Since the 1980s, several research groups have created environments and prototype buildings of so-called smart buildings. Based on Ken Sakamura's T-Engine Hardware and a complementary operating system, the Tron Houses 1, 2 and 3 have been built [15]. The US AwareHome [16] and PlaceLab [17] follow a similar approach and MIT's House_n [18] even includes modular intelligent furniture that can be equipped with various sensor systems. Recently designed German prototypes of assistive homes, such as “Haus der Gegenwart” (house of presence) [19] and “Haus der Zukunft” (house of the future) [20], are exemplarily equipped with a variety of networked pervasive technologies integrated by modern design. Similar to our approach, smart buildings and robotic rooms try to integrate sensor-actuator systems with architectonic elements. However, these approaches primarily integrate sensors, actuators and robots on an informational level. Furthermore, they are presenting implementations that are realized in a controlled experimental environment, and cannot be straightforwardly applied into a regular medium sized apartment to serve as an integrated assistive system for ADLs.

The multi-dimensionality of assistance, which is the ability to serve a variety of constraints simultaneously, can be created by robotic environments due to the expected multi-morbidity in aging society which usually leads to complex, individual and multiple constraints [21]. Conceptual foundations for assistive, robotic rooms that are generated by compact room-in-space elements have already been set out by the authors in [22].

1.2. Research question and method

From the background described above it can be concluded, that the real-world utilization of assistive, robotic elements, i.e. robotic rooms for the purpose of ADL-assistance and care would provide a multitude of opportunities for future gerontechnology. Most previous approaches, however, are focused on the pure research aspect and not on an adaptation of concrete scenarios in collaboration with users and other determining factors such as the manufacturability of the system and its integration into an overarching value system. Research has so far failed to address the question how basic research in robotic rooms could be translated into real world applications resulting in a lack of knowledge and guidelines. How could the idea of assistive, robotic rooms be translated into practical and user accepted approaches? How could those approaches add value to the life of elderly people, their relatives and caretakers? How could robotic elements be efficiently manufactured and integrated into existing and newly constructed buildings? What product structures and business concepts would be reasonable and should therefore be considered as inputs for design and engineering?

The LISA project attempts to address the existing lack of knowledge and guidelines by developing, testing and evaluating RmR systems according to standard residential configurations. In this project, the user is in the foreground. As elderly people are less receptive to new and more complex technology, it must be discreetly embedded in these RmRs. The control of the embedded intelligent systems is possible through intuitive gestures and voice commands which ensure that even elderly people can easily familiarize themselves with the operation [23,24].

In the LISA project, a dedicated modular approach has been followed to form the basis for a cost efficient system development by the participating corporate partners. The approach pursues relatively recent modularization strategies in architecture and construction [25,26], which are already connected, for example in Japan, with an automated production of buildings and building elements [27]. Such strategies, especially in the Ambient Assisted Living (AAL) field, have been implemented and investigated in [28]. Consequently, a comprehensive product architecture was created, physical-wise and information technology-wise, as well as a furniture-like wall element, (Fig. 1), which creates the basis for the various functions of the RmR described in LISA: (i) new assistive functions can be “plugged in”, (ii) remote access to i.e. vital signs data by a physician or care provider via internet, and (iii) the platform can be further expanded to be integrated into other furniture wall units in other residential areas (scaling of the system).

Aside from the experimental development of the RmR prototype, the project was aimed at covering all necessary levels of value creation i.e. marketing, development, manufacturing, installation and maintenance. Besides the technical development dealing with embedding RmRs in business models, the option to transfer the installed terminals' information, communication and building technologies into household and nursing-related service providers was also emphasized.

The research project LISA is located in the field of translational research. The methodological objective of the project is to translate the approach of RmRs into specific applications within the residential environment. By following an iterative experimental procedure, not only initial application possibilities were generated by the project, but methods were also tested for the systematic training between the technical bases and the concrete, industrially usable use scenarios.

To ensure scientific progress in each phase of the project, the project was divided into four phases of development. In every phase of development, analyses were first performed, followed by a concept initial development, a specification phase and a final collection of user feedback and evaluations. User feedback and evaluation formed the starting point for the follow-up project LISA “Habitec” (habitat, Bits and Technology in an Aging Society) which deals with installing RmRs within the entire apartment, thus expanding the current system to further Life Centers.

Thus, these RmRs designed in a way that they do not replace existing walls, can facilitate cost effective affordable solutions for elderly people, even those with limited income or resources. Furthermore, the RmRs are planned in a way that for each Life Center in the home environment, an individual terminal is deployed. Thus, each terminal is designed and developed according to the associated Life Center and according to the technologies and services that the user requires with respect to the corresponding ADLs.

These first 6 Life-Centers were identified in an apartment and sorted according to their complexity (1 = not very complex, 6 = most complex): 1 entrance, 2 relaxing, 3 living, 4 working, 5 food and 6 body care. The evaluation criteria consisted of the installation complexity (piping, cabling, necessary subsystems, design effort, etc.). As far as the project LISA is concerned, the entrance terminal was developed, as this was the least complex one, and additionally will enable the knowledge and experience gain for further development of more complex terminals for Life Centers 2–6.

Several prototypes have been developed and evaluated in terms of ergonomics and ease of use in the above-mentioned iterative and experimental 4 phases of development: phase 1: Interview with elderly people regarding the design and multidimensional assistance, phase 2: Development and evaluation of the first mock-ups using an age simulation suit (Fig. 2a), phase 3: Evaluation of prototype 1 with real test users (Fig. 2b), and phase 4: Long-term evaluation of refined prototype (prototype 2) in a real home environment (Fig. 2c).