Co-adaptation of Assistive Mobility Devices and Residential Functions

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Purpose For facilitating an independent living for elderly or disabled people, a method has been developed at TUM Building Realization and Robotics Lab, which aims at creating intelligent living environments by adjusting mobility systems and everyday objects (e.g. appliances) as modular and complementary subsystems[1]. The proposed system comprises an intelligent wheelchair, which enables simplified use of the bath-room, kitchen and living room, etc. It can dock at certain functions, e.g. the toilet, both on a physical and information technology level. **Method** Studies show that the major problem for people with physical and/ or cognitive disabilities in everyday routine and in managing the Activities of Daily Living (ADLs) is the surmounting of different height levels and distances. Even for a person with a good physical fitness, it is extremely difficult or even impossible to transfer from a wheelchair onto a couch autonomously. The reason is the height difference between the furniture and wheelchair, as well as the space or gap that occurs mostly between the transport device and the piece of furniture. The proposed work presents a thorough research study, which enabled a huge gain in knowledge, concerning the re-design of household appliances and devices, in order for them to be straightforwardly and cost effectively integrated with mobility supporting robots[2]. The outcome of this research, led to the participation on a research project which involves 7 companies and 3 universities. In order to realize the co-adaptation of an assistive mobility device and residential functions, the following development approach steps were followed: i) research and identification of needs, ii) definition of requirements, iii) identification of technologies and processes, iv) initial concept, v) experiment in real environment, vi) final concept and further development roadmap. **Results & Discussion** Most wheelchairs are designed with a fixed height and do not provide features for altering their elevation level. Additionally, handicapped individuals face major problems when reaching items located higher, due to the fact that objects in the environment are mostly located statically, and it is difficult to get at them as a disabled user. Especially for disabled people, the functions should come to them instead of the other way around. The results of the study prove that the co-adaptation of assistive mobility devices[3] with various residential functions, allow the complexity reduction of mobility robots. Companies notice a huge potential in such an approach, as it would allow them to design less complex, and thus more cost effective robots for ADLs use. The high cost of robots is currently one of the main obstacles for deploying them in the home environment. Based on this study, TUM was finally able to set up a government funded 3-year R&D project (total funding cost: 3.9 Million €, starting from June 2012) where major strategies, processes and components necessary to achieve uninterrupted mobility chains for elderly people will be brought to product market level.

***Keywords**: mobility & transport, ambient integrated robotics, assistive mobility, demographic change design*

INTRODUCTION

The current world population comprises more than 7 billion people. This figure increases enormously, although the population in industrial countries is declining. In contrast to developing countries the consequence in industrial ones is demographic change, Figure 1. This means that the population is aging over time, reducing the fraction of the population in working age. This process is driven by falling mortality rates followed by a decline in birth rates, which reduces population growth rates (and even turn them negative in some countries). While demographic change occurs in all countries worldwide, extent and timing differ substantially[4]. Europe and Asia countries have almost passed the closing stages of the demographic transition process while Latin America and Africa are only at the beginning[5, 6]. The older population's stratum becomes more and more important to focus on.

This study deals with a way to assist old age people. The first phase of the project comprised research on activities of daily living and the state-of-the-art technologies. That was followed by experiments to find out difficulties. These difficulties were analyzed and assessed. The results of this procedure influenced the concept which can be divided into architectural, social and network part. Finally an interesting solution approach was proposed.

RESEARCH AND SURVEY

Activities of Daily Living (ADLs)[7] represent tasks in everyday living, that people usually need to be able to manage as independent adults. Basic ADLs (BADLs)[8] consist of self-care tasks, including:

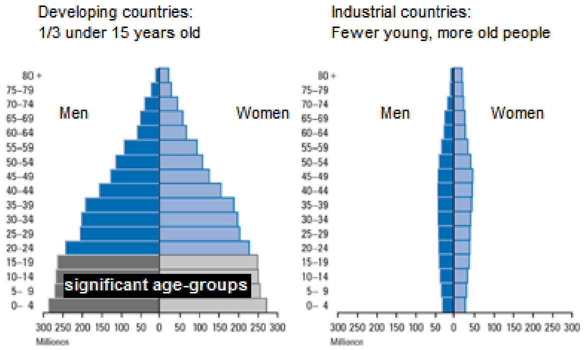

Fig.1. Population by age and gender

personal hygiene and grooming, dressing and undressing, self feeding, functional transfers (getting into and out of bed or wheelchair, getting onto or off toilet, etc.), ambulation (walking without use of an assistive device such as walker, cane, or crutches, or a wheelchair). More complex skills are defined as Instrumental Activities of Daily Living (IADLs). IADLs are not necessary for fundamental functions, but they allow an individual live independently in a community[9]: housework, taking prescribed medications, managing money, shopping for groceries or clothing, use of telephone or other form of communication, using technology (where applicable), transportation within the community. The defined routine tasks, such as bathing, dressing and eating, can be used as a base for assessing the independence of elderly people.

Difficulties are often introduced in subsequent developments for supporting and assisting the ageing society. Even if the technology assists and supports the daily living in an optimum way, the technology acceptance is negligible by the majority of the elderly individuals. Either due to the purchase costs, or to the technological complexity involved in these products, which makes them difficult to be managed and operated by an old person. A wide variety of wheelchair designs already exists in the market (Figure 2).

Fig.2. Wheelchair example implementations

Some are more realistic and others are more futuristic. Several designers try to find different solution approaches for diverse problems. Thereby, a wheelchair should guarantee the best possible freedom of movement.

Also the Toyota automotive manufacturer company, which is dealing with the issue of mobility, developed supporting systems called Welcabs[10]. The main idea behind Welcabs was to assist elderly and disabled people to easily get in and out of a car. The implemented designs differ from additional ramp to movable car seats (Figure 3).

Fig.3. Toyota Isis: Rotating and sliding rear seat model based on the Welcab concept

Nevertheless, one of the main challenges ageing society is facing, is not only to get in and out a car, but the functional transfers like getting into and out of bed or wheelchair, getting onto or off toilet (Figure 4), etc.. An approach to solve this problem would be either to adapt the environment arrangement to the specific functional transfer needs, or to optimize the wheelchair design and features. The optimal solution though is to find a combination utilizing both these two alternative approaches.

Fig.4. Toilet functional transfer problem

Experiments

Locomotion with a wheelchair restricts the everyday life in a great extent. Normal routine tasks like getting into and out of bed comprise a challenging process. Therefore experiments were conducted dealing with functional transfer issues in order to identify the difficulties and limitations involved in these processes.

Living room

A typical living room problem elderly and impaired people are facing, is to transfer from the wheelchair onto a sofa. The experiment shows the existing height difference these people have to compensate when they want to sit down on the sofa. Additionally, even if the sofa and the wheelchair had the same height level, it is impossible for someone to transfer to the sofa without the assistance of a second person, considering the arrangement depicted in Figure 5.

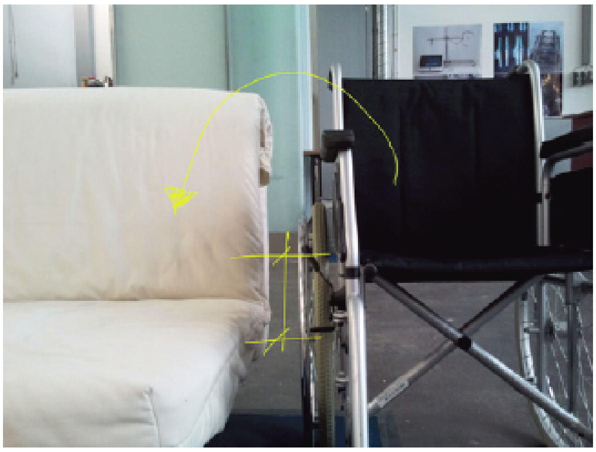

Fig.5. Living room sofa-wheelchair transfer

Kitchen

The furniture in a standard kitchen have standardized dimensions, in order to comply with global standards that were predefined to allow the installation of universal size appliances such as electric stoves, fridges, dishwashers, etc.. Without any adaptations for wheelchair users, there are a lot of disadvantages identified by the experimental procedure. According to Figure 6, restrictions and limitations are introduced when retrieving items from the shelves or want to use the tap and the sink.

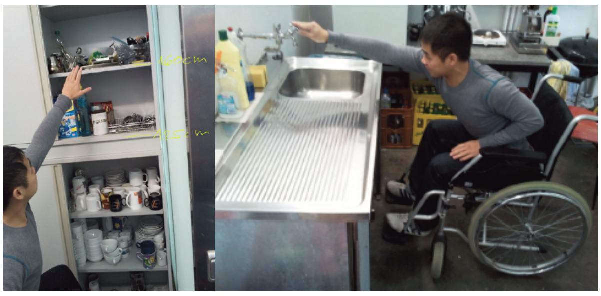

Fig.6. Kitchen environment issues

Dining/Working room

The last part of the experiment was to define the limitations wheelchair users are facing while approaching a dining table or a working desk (Figure 7). Once more it was observed that it is impossible to approach close enough to the table area, due to restricted height dimensions, since the wheelchair does not fit under the given height. One might say that this problem can be easily overcome by increasing the demanded table height dimension. The disadvantage this solution imposes is that instead of adapting the wheelchair structure to most of existing table heights, in order to enable compatibility to many different situations, the table is adapted to the given wheelchair, implying thus a unique solution that cannot be applied to more everyday activities.

Fig.7. Dining room/Work room

Results

The conducted experiments allowed a series of observations and conclusions. The major problem identified though, is the different dimensions existing between wheelchair height and the test subjects. Table 1 indicates the aforementioned problem.

Living room

The executed tasks seem to be impossible to be perform by old people sitting in a wheelchair. The distance between sofa and wheelchair is too wide and additionally a great height difference also exists. A further obstruction is also the armrest of the wheelchair. Since the armrest is not foldable the wheelchair couldn't be placed ideally along the sofa. Even with enormous efforts it seems to be impossible to transfer to the sofa.

Kitchen

The heights of the shelves and accessing the kitchen worktop can be a problem for the corresponding individuals. Wall cupboards are almost impossible to be used. The main difficulty observed while using the kitchen worktop is that there isn't usually any free space under it to place the wheelchair.

Table.1.Limitations imposed in wheelchair functional transfers/activities (i:impossible, s:slight, m:medium, h:high, n:normal)

Area	Action	Difficulty level				Acci-dent risk		
		i	s	m	h	s	n	h
Living room	Sofa / Bed → Wheelchair	x						x
	Wheelchair → Sofa / Bed	x						x
Kitchen	Shelf height: 10 cm			x			x	
	45 cm		x			x		
	80 cm		x			x		
	125 cm		x			x		
	> 160 cm	x				x		
	Sink				x	x		
	Water tap	x				x		
	Kitchen worktop				x	x		
Dining/ Work-ing Room	Move the wheel-chair towards table		x			x		
	Move the wheel-chair away from table		x			x		
	Eat and work		x			x		

Dining/working Room

Since the wheelchair cannot be, in most situations, fitted under the table top, (unless using a relatively higher table), difficulties are introduced in case the individual requires to either eat or work efficiently using the table or desk area.

CONCEPT

Using the results obtained from the various experiments conducted, a mock-up for an optimized wheelchair was designed and a concept was realized. The concept can be divided into three parts: architectural, social and networking concept.

Architectural concept

In a standard apartment there are several rooms, each of them with different functions. Some rooms are hardly ever used, mainly because the different height levels often constitute a challenge. The function of the room can be structured and summarized. Functions with installations, such as kitchen and bath, are integrated together eliminating the existing separating walls in between. By placing functions together, a type of cell structure is introduced. Thereby this cell is built as modular system and can be individualized. An important issue is to design and implement a cell fusing most of the apartment functions, while leaving the rest of the apartment barrier-free, in order to be unrestrictedly used by a wheelchair user. In Figure 8, the proposed architectural concept is presented, where the motion analysis depicted paths, prove that a centralized function cell, reduces the required transport needs of the impaired user.

Networking concept

Nowadays, networking undoubtedly comprises a necessary service. Optimized networking systems offer enhanced service delivery, extend the communication barriers, and improve quality of living. Databases and information exchange platforms, enable access to various kinds of data, either from defined places or user defined terminals, while presenting the feature of data synchronization on different appliances and devices. The aim is to integrate such platforms in the proposed cell structure and also connect them to services, for example tele-care, domestic aid, security, and infotainment. This can contribute in enhancing the quality of service delivery to isolated elderly or disable people, and assist them in discovering new possibilities and ideas.

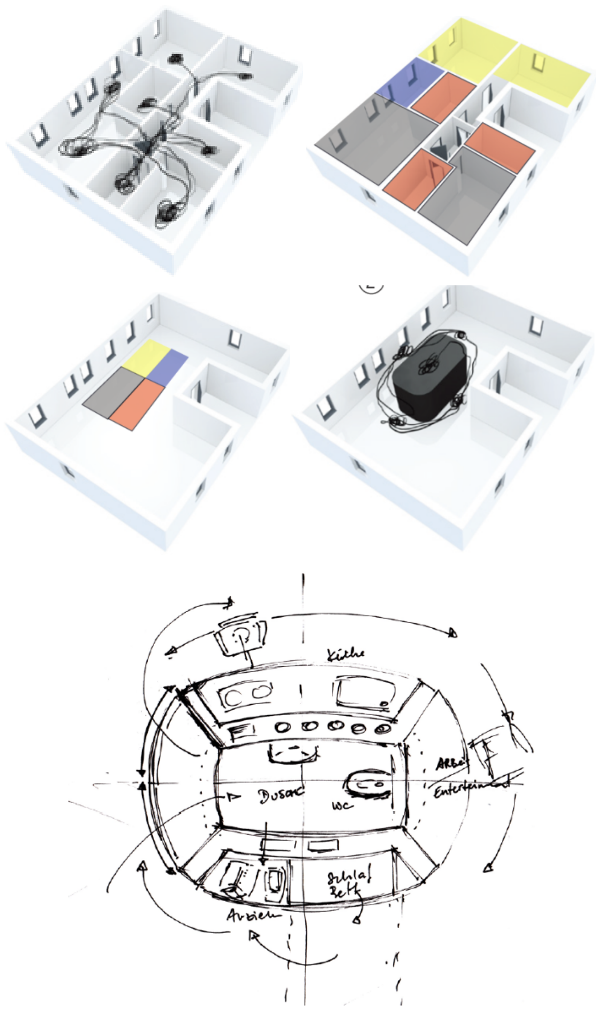

Fig.8. Proposed architectural concept, top left: Standard apartment, top right: Different functions, middle left: Centralized functions, middle right: Cell, bottom: Initial Concept

Social concept

Especially for elderly people the social connection is an important missing option of their daily routine. Elderly people spend more time in their home environment, either due to disabilities or to health condition issues. Communication with their social network is explicitly achieved over the telephone, which is a very limited, in terms of features, type of communication. Nowadays social online networks are more common and more integrated. Elderly people on the other hand, are not very familiar using the World Wide Web. It must be noted though, that today's young generation comprises the senior generation of the future. Thus the existing technologies ought to be adapted to this situation. However the physical social networking is not negligible as well. Approaches should be proposed on how to design the ground plan for apartments addressed to elderly people. Two main types of areas are proposed: private and public ones. A harmonic combination of these types could affect in a positive way the daily routine of elderly people (Figure 9).

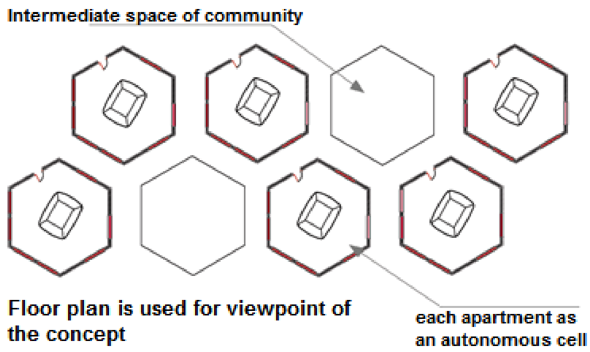

Fig.9. Social Concept

Solution Approach

The proposed concept aims to implement a modular system which is an optimized combination between a wheelchair and fixed installation modules. Unnecessary partition walls will be removed, allowing only the main cell to dominate the area fusing main functions of ADLs like eating (kitchen) and bathing (bathroom –toilet). Furthermore, the specially designed wheelchair enables the best possible mobility within the area, while at the same time communicates in an informational level with the cell, in order to exchange data acquired by its built-in sensors. The proposed concept is depicted in Figure 10.

The cell installation could be designed as a core of the apartment. It is the main part of the concept and contains most of the functions assisting in ADLs. It supports the independence of elderly people with optimized furniture and shortened transition paths. Due to its modularity, the cell can be individualized according to the user needs, or even upgraded.

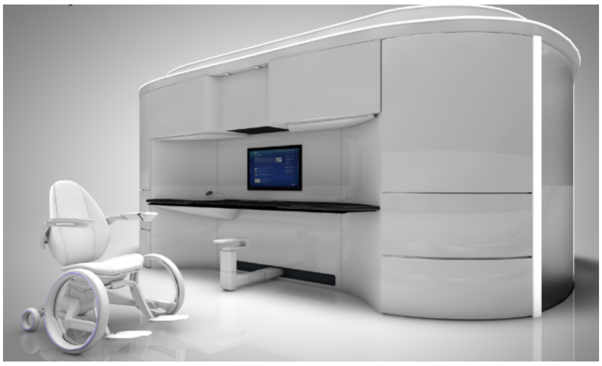

Fig.10. Proposed concept

In the centre, there is the personal hygiene and grooming area, i.e. toilet and bathroom (Figure 11). Depending on the user it can be equipped with a standard toilet and bathtub/shower, or considering a wheelchair user it can be equipped with an optimized toilet and shower. A central rotating platform mechanisms embedded in the floor, supports the mobility of a wheelchair by rotating the user accordingly to the desired function in the bathroom. An integrated communication platform, allows data exchange between the different available services. For example the vital signs data of the user, measured by the inbuilt sensors of the wheelchair, could be sent to a physician for a remote checkup.

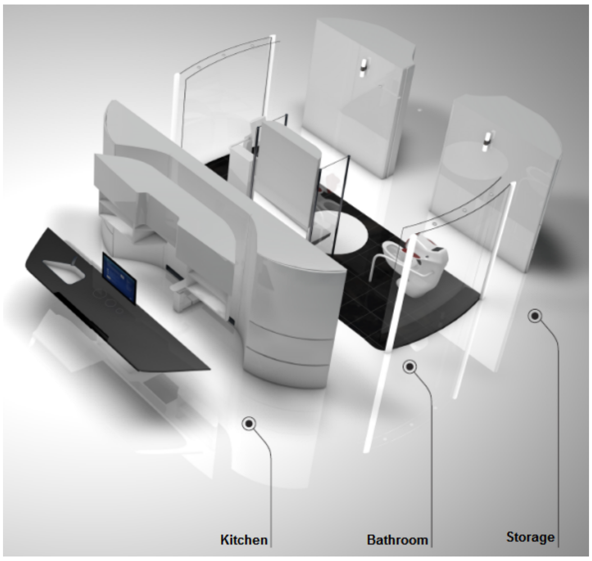

Fig.11. Functions of the proposed concept

The wheelchair consists of three main components: the substructure, the central axis and the seat. Extensive attention was given on the transfer of the individual between the wheelchair and the cell elements. To reduce the user efforts the chair is motorized offering a lift function. The most important component is considered to be the seat and the armrest with the built-in sensors. The collected data are sent using WiFi technology to the cell communication platform, where they are accumulated and stored.

These can then be evaluated by an expert and / or retransmitted back to the cell.

The majority of the embedded sensors comprise vital sign measuring devices that are embedded on the wheelchair in order to seamlessly acquire readings. A respiration frequency meter, a weight analysis meter (measuring BMI-index), a Electrocardiogram sensor (EKG), and activity logger sensor on and around the chair, and a infrared pulse oximeter (to monitor oxygenation of user hemoglobin), are integrated in the chair's vital sign sensor features. These offered features are presented in Figure 12.

The proposed research and realized concept formed a basis in creating a multidisciplinary consortium, involving academic and industry partners, leading to a research project in the field of Ambient Assisted Living (AAL) called PASSAge. PASSAge is a 3 year BMBF-funded R&D project (June 2012 – June 2015) with a total cost volume of 3.9 Million €. Besides the authors, 9 other academic and industry partners form the consortium. The concept described in the proposed paper, are going to be further developed and finally implemented during the research project duration. The involved industry partners, such as Streifeneder[11], are already active in implementing products and assistive mobility devices focusing in disabled individuals, Figure 13.

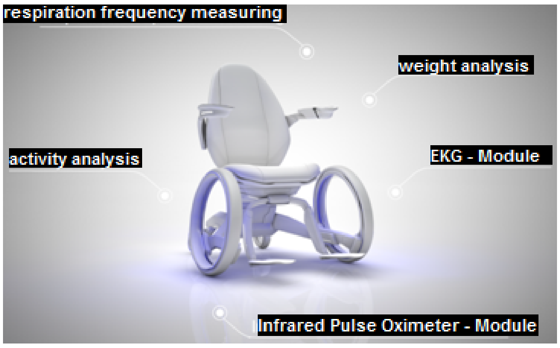

Fig.12. Proposed Wheelchair embedded sensors

Conclusions and Future Development

The proposed concept addresses the mobility issues within the ageing society by developing a modular and personalized mobility system that can be integrated into the individual surrounding of the user, enhancing the quality of everyday living by encouraging individual mobility, as well as providing safety, comfort and health. Adaptable, customizable and user-friendly add-on modules (operation and shopping assistance, health phones, transfer support at the entrance of buildings or within buildings) are being adapted by existing technologies and innovative mobility components from the field of personal mobility devices (e-bike, e-rollers, e-car, trolleys), which are already equipped with various technologies (ICT, micro-systems). The concept aims to implement a modular system which is an optimized combination between a wheelchair and fixed installation modules. A co-adaptation of assistive mobility devices with various residential functions is proposed, allowing thus the complexity reduction of mobile robots. Companies notice a huge potential in such an approach, as it would allow them to design less complex, and thus more cost effective robots for ADLs use. The high cost of robots is currently one of the main obstacles for deploying them in the home environment.

Fig.13. Intelligent wheelchair assisting in functional transfers

References

1. Bock, T., *Robot Oriented Design*, Shokokusha, Tokio, 1988.
2. Fusero, P., *E-City: Digital Networks and Cities of the Future*, Ed. Sense-able City Lab of Massachusetts Institute of Technology, 2008.
3. Mitchell, W.J., Borroni-Bird, C., Burns, L., *Reinventing the Automobile: Personal Urban Mobility for the 21st Century*, MIT Press, 2009.
4. Krueger, D., Ludwig, A., "On the Consequences of Demographic Change for Rates of Returns to Capital, and the Distribution of Wealth and Welfare", *Journal of Monetary Economics*, Vol. 54(1), pp. 49-87, 2007.
5. Bloom, D., Williamson, J., "Demographic Transitions and Economic Miracles in Emerging Asia", *World Bank Economic Review*, Vol. 12(3), pp. 419-455, 1998.
6. United Nations, *World Population Prospects: The 2002 Revision*, United Nations Population Division, United Nations, New York, 2002.
7. Wiener, J.M., Hanley, R.J., Clark, R., Nostra, J.F. van, "Measuring the Activities of Daily Living: Com-

parisons Across National Surveys", *Journal of Gerontology*, Vol. 45(6), pp. 229-237, 1990.
8. McDowell, I., Newell, C., *Measuring Health: A Guide to Rating Scales and Questionnaires*, 2nd edition, New York: Oxford University Press, 1996.
9. Bookman, A., Harrington, M., Pass, L., Reisner, E., *Family Caregiver Handbook*, Cambridge, MA: Massachusetts Institute of Technology, 2007.
10. Welcab, http://www.toyota.co.jp/en/kids/man/welcab.html, 2012
11. Streifeneder, http://www.streifeneder.de/, 2012.