Design of a Multifunctional and Modular Bed System

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The design study outlined in this paper was carried out as part of a Master Thesis while utilizing the REACH project as a use case. The paper deals with the upcoming difficulties of demographic change and the declining number of medical staff or family members who provide care for the elderly. Since a patient is expected to spend most of their time in and around the bed, it was concluded that bed is the ideal place to start effective interventions. A modular system, which allows modules with various functionalities to be integrated into the hospital bed, were developed. Such intelligent multifunctional modules with high-technology elements support patients and nurses in their tasks all day long. The system aims to provide a value-based care environment that keeps the elderly healthy. The modules can be modified depending on the health condition of the elderly.

***Keywords**: Hospital bed, Ambient assisted living (AAL), Modularity, Activities of Daily Living (ADL)*

Introduction

The concept and design proposed in this paper deals with the difficulties that the future society will face. Even today, only a small number of people in industrial countries choose to look after their elderly parents. Moreover, their number is expected to further decline in the coming years. Most people concentrate more on their professional success rather than on the wishes of their parents staying in their own homes. The obligation for the care of the elderly is being transferred to nursing facilities. This progress is further aggravated by the growing number of childless couples due to demographic change.

Since the healthcare systems in the EU are mostly financed by employees' social insurance contributions, the increasing share of retirees reduces the contribution to health care. The demographic change will be a significant challenge for the EU countries. Also, the supplies for the elderly population, who are highly susceptible to diseases, will result in an enormous financial burden. Consequently, the number of dependent elderly will rise, and this will, in turn, increase the demand for long-term care services and facilities[1].

The EU is trying to counter the problems of the demographic change with investments such as HORIZON 2020. HORIZON 2020 is a framework program for research and Innovation aiming to keep the elderly active and independent for a more extended period[2]. As part of the HORIZON 2020, the “Responsive Engagement of the Elderly promoting Activity and customized Healthcare” (REACH) project develops new technologies and services for a value-oriented and patient-centered health system in the future[3]. To achieve this, special Active Assisted Living (AAL) technologies are of interest.

Analysis

A deep understanding of general and context relevant problems was needed to develop a sophisticated concept. For this purpose, great importance was attached to close cooperation with the stakeholders, especially with the end users and the caregivers. Early in the analysis process, it became clear that the bed is the ideal place to start effective interventions: patients spend most of their time in bed.

Analysis of Diseases and problems for elderlies

Patients cannot be generalized; "the" patient does not exist. People differ remarkably in age, social skills, level of education and especially in their health conditions. But according to the stakeholders, the following are the main problems/diseases affecting REACH’s end users: Dementia, Decubitus, Incontinency, Dependency, Frailty, and Loss of Social Inclusion. These problems, and taking into account the hospital bed context, it was also prudent to analyse in detail the sleeping difficulties. A system that can adapt flexibly to a person and her/his changing state of health has therefore to be developed.

Analysis of state-of-the-art sleeping environment

The knowledge about the current sleep environment trends and the state-of-art of the research of this topic is needed to develop a new and innovative concept. As a central element in the patient’s hospitalization, the bed has an important and special position. A hospital bed must overcome a variety of challenges; for example, it must be comfortable. The bed should provide a high lying comfort through adaptive dimensions according to the patient[4], and the patient should be able to change into a sitting position as easily as possible.

Also, the transfer of the bed-ridden patient in and out of bed is often a big challenge. Usually, the patient is

supported in this progress by the bare hands of a caretaker. With time, this can also damage the health of the caretaker. A bed with adjustable bed height facilitates the transfer and allows the caregivers to raise the patients to a level where they can comfortably take care of them. Panasonic invented a new solution for the transfer problem where no help from a nurse is needed[5].

Patients in the Intensive Care Unit (ICU) have to perform the so-called "early mobility"[6]; the transfer of a patient from the lying position into sitting or vertical positions. The passive standing by a standing frame aims to improve respiratory function and cardiovascular fitness, increase the levels of consciousness, functional independence and psychological well-being and reduce the risk for delirium and the adverse effects of immobility[7]. One example of a bed with which ICU patients can accomplish early mobility is the Sara compilizer by Arjo Huntleigh[6].

Of significant concern, however, is the absence of novel technologies in and around the hospital beds on the market, despite the fact that there are some new concepts and ideas in research. Additionally, there is an increasing market for sleep monitoring devices for private consumers. The number of people suffering from sleep disorders, snoring, restless legs syndrome and sleep apnea are rising[8]. Devices like bed sheets with integrated sensing systems[9] and a sleeping mask with integrated EEG[10] should help to diagnose sleep disorders early, and to detect possible causes. The user usually has access to the results through their cell phone or tablet. Besides the sleeping habits, some devices can also detect vital signs like breathing and heart rate and the environment[9].

Modularity and platform strategy

The concept of the bed should consider a feasible production of the bed for a large market. Nowadays, customization is essential to the success of a product. Therefore, modularity is used to achieve mass customizations. Mass customization reduces the expenses and at the same time maximizes on individual customization. Six basic types of modularity are present in modular products: Mix Modularity, Bus Modularity, Sectional Modularity, Component-Sharing Modularity, Component-Swapping Modularity and Cut-to-fit Modularity[11]. To save on development costs, the Component-Sharing Modularity (through the same speed and angle sensors) was used in all training modules, and the Bus Modularity was used in the concept.

Also, the so-called platform strategy is interesting in this context since it allows savings, ease of manufacturing and provides structured modularity at more levels with a high degree of standardization[12].

CONCEPT

Bed-to-chair-transformation with verticalization function

Most of the time in the hospital, the life of the patient revolves around the bed. Because of physical limitations, patients can only carry out activities like sleeping, eating and spending their leisure time in their bed. The latest hospital beds[4] already have the function allowing patients to occupy a sitting position. In this design, the bed can turn itself into a real chair, allowing the bed to support the patient and the nurse to carry out multiple tasks such as eating. An interview with the hospital facility management revealed that it would be useful if the bed could also be placed in a vertical position (see Fig.1).

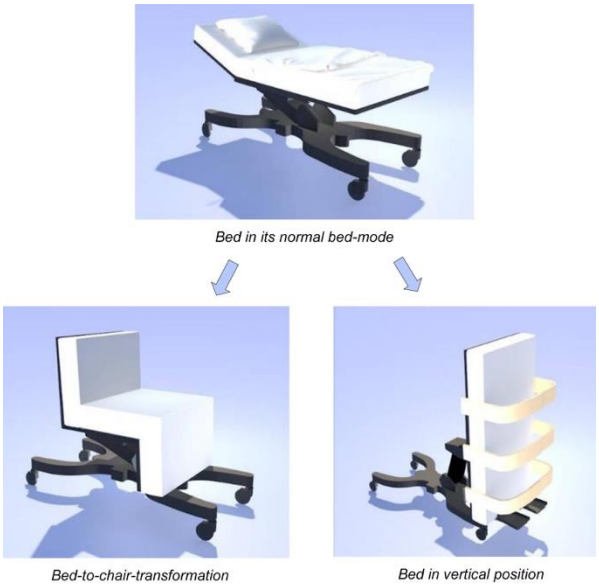

Fig.1. Bed as a normal bed, in its chair mode and the bed in vertical position.

Bed as “docking station”

As shown in Fig.2, modules (each with a specific task) have been developed for various functions. These modules can dock at different positions on the frame of the bed. Most conventional modules, however, would be able to dock themselves only at the front part of the bed. The transfer module, anti-decubitus module and the butterfly-shoulder-press training module would be able to dock on the back. The monitor module, the urine-/catheter cover module and hygiene module can dock at any position, even on the side of the bed. All the modules are symmetric and self-guided with every designed module having a similar appearance. The aim of module design is to express unity among the several modules.

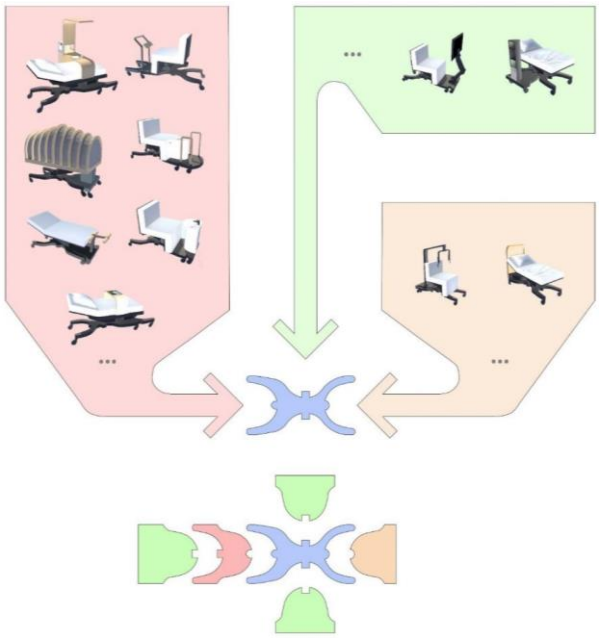

Fig.2. Bed as "docking station.

The modules will be stored in a special module storage room such that the modules can be used by different patients, and such a smart storage system prevents wastage of the limited space in the hospital. The docking and undocking can be carried out manually by a nurse and informal caregiver or fully automatically by the robot Pioneer LX[13]. Thanks to a special manipulator, the robot can dock at each module and pull/push the modules to the hospital bed. To dock, the robot has then to push the module back to the bed or another module.

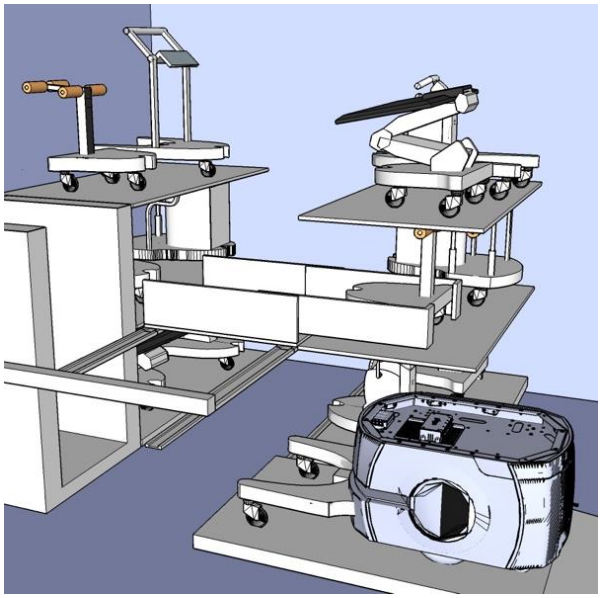

Fig.3. Smart storage system for the modules

Different level of platform strategy

As a basic first level requirement, the role of the platform is to function as a hospital bed. In the second level, individualization is achieved by docking the modules. Nurses, patients, their guests or Pioneer LX can readily perform this task. For the expansion and changes after second level individualization, in the third level, professional staff are needed. Special sensors are installed according to the specific needs of the patient.

Tab.1. The three level of the platform strategy

Level 1:	Bed = Platform
Level 2:	Individualization by add-on Modules
Level 3:	Further Individualization by Plug-Ins as Sensors

Fig.4. Examples for the three level of the platform strategy

DESIGN

An essential factor in the design of hospital furniture, which, unfortunately, is often neglected by many manufacturers is the hygiene. To make this process easier during the design of the bed and modules, special attention was given to ensure the absence of holes and grooves. Moreover, large and easy to clean surfaces should predominate. Also, the integration of the electronics in the bed should be considered. Friction and moisture can damage the electronics. Therefore, all electronic devices and wires have to be covered or integrated into the structure of the furniture. Lastly, easy to clean materials should be used.

Hospitalization is an annoying situation for every patient. To make them feel safer and more relaxed, the appearance of the surroundings is vital. Since the hygienic guidelines strongly restrict the selection of the materials, the design is focused on shaping and colouring. Friendly colours and curved shapes should be inviting to the patient.

In emergency cases like a heart attack, the doctors have to quickly reach the back of the bed to start resuscitation measures. For this, the modules docking on the back (Transfer Module, Anti-Decubitus Module and the Butterfly-Shoulder-Press Training Module) and the modules which can dock on every position (Monitor Module, the Urine-/Catheter Cover Module and Hygiene Module) need an easily accessible emergency button. If this button is pressed, the corresponding module is automatically undocked from the bed and medical personnel can manually push the module away.

An Overview of the designed modules can be seen in Fig.5. In this paper, a few selected modules.

Fig.5. Overview of the developed modules.

Basis Bed

As a platform, the bed is the central element in this system (see Fig.6). By docking on the bed, the modules can extend its functions. The analysis of the state-of-art revealed that the bed should be able to take a sitting and a vertical position. When this is done electronically, the patient can readily control this process by a control device.

As already mentioned, patients spend most of the time in their beds during hospitalization. Often in hospitals, the nurses transport the bedridden patients to and from the operating rooms and treatment rooms. Given the vast number of beds in a hospital, the nurses can easily lose the overview and may not know where a particular bed is. Beds having installed navigation sensors can easily be located in the hospital and prevent lengthy searches of the beds.

Additionally, a light barrier in combination with a pressure sensor can detect if the patient has left the bed and send a signal to the nurse for intervention. For example, preventing accidents by a sleepwalker or letting a dementia diseased person to run away unnoticed. As soon as the patient leaves the bed at night time, the system automatically activates a LED lighting system integrated into the bed, therefore minimising the risk of falling. If required, the bed can be expanded using a fall-prevention add-on module.

The height of the bed can also be adjusted. On the one hand, this makes it possible for the nurses to work with the patients in a height which is pleasant for their back. On the other hand, the chair can be adapted to the low height of any wheelchair in its chair mode, thus facilitating the transfer of the patients. The smaller distance to the floor also reduces the risk of injury to the patient in the event of a fall.

The basic functions of the bed are the height adjustment, and the transformation to a chair or to the vertical position. The navigation sensors, the LEDs, the light barrier and the fall prevention are conceptualized as modular add-ons.

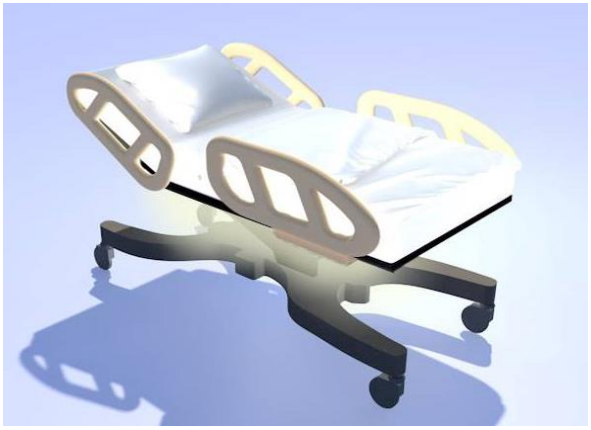

Fig.6. Basis Bed

Toilet Module

In high age, simple everyday tasks such as using the toilet are challenging (Fig.6 depicts a module which aims to solve this problem). After getting up, before going to sleep and whenever the patient needs to visit the toilet during the day, the toilet module can be used. This module is highly beneficial to patients with urge

incontinence (a sudden urine loss) as a result of the uncontrollable contraction of bladder sphincter. This Syndrome occurs more frequently in high age. Often, many elderlies have problems - mainly if they are physically restricted - to reach the toilet in time. Also, Hard-to-open doors can become an insurmountable obstacle, and the patient has to suffer from a shameful experience.

The toilet module is simply and quickly docked to the chair with the toilet seat located between the patient's legs. In this position, the elderly can easily slip to the toilet aided by the handles on both sides of the toilets. The round shape of the toilet helps the patients to get their legs more conveniently to the front, without being injured by the edges.

After use, the nurse can, in a hygienic and convenient manner, take the stool and the urine from the urine collector for further appropriate urine diagnostic tests. In urine diagnostics, the physician checks the exact composition and contents of the urine and can thus draw conclusions about the presence of diseases such as diabetes (a standard method in hospitals). Nevertheless, some patients have problems filling a small cup with their urine. In the toilet module, this is done automatically during regular use without water contaminating the urine sample. On the toilet seat, four electrodes that can detect the electronic signals of the human body and calculate the resultant impedance are attached. With the electrocardiogram (ECG), a wide range of statements on the characteristics and health of the heart can be made[14]. The sensors used in these modules should work unobtrusively.

The technical innovations of Japanese toilets are also to be found in this toilet. The toilet seat provides highly-efficient automatic deodorization, automatic cleaning, a heated closet seat and drying with warm air[15]. For the toilet module, special attention was given to hygiene and a stable plastic material which is both resistant to moisture and easy to clean was used.

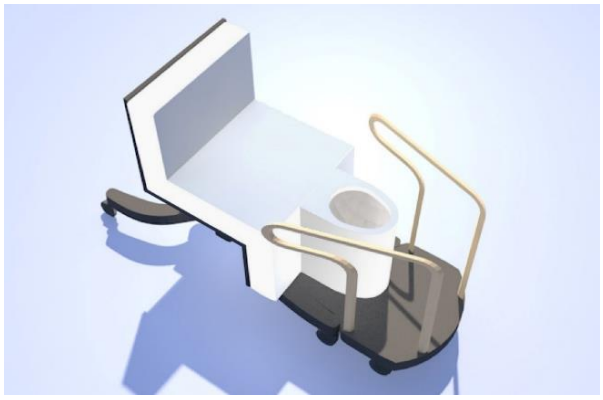

Fig.7. Toilet Module

Training Module

Many problems of older patients like frailty and dependency depend on the loss of muscle mass in advanced age. If this is not treated in time by targeted training, a vicious circle is created. The following exercises have been specially designed to train all essential muscles to perform ADL. Fig.8 shows all training devices implemented as modules with their target muscles.

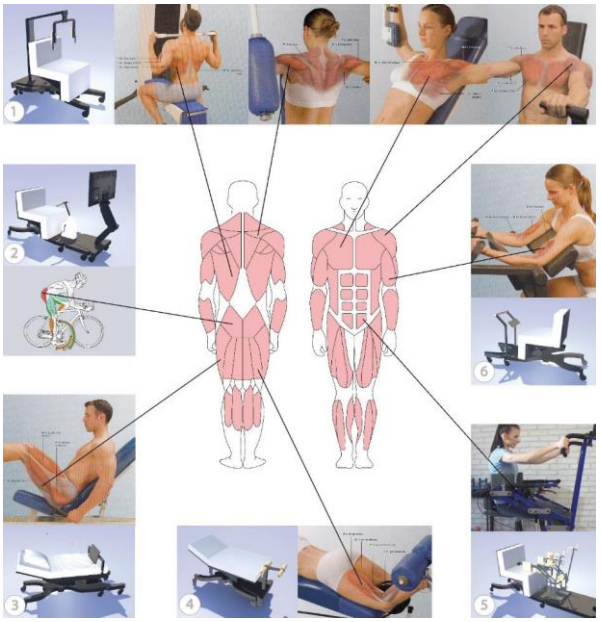

Fig.8. Muscles required to perform AAL and the corresponding training devices [16, 17, 18]

Monitor Module

The Monitor Module is one of the few modules which can dock at all slots of the docking stations and on the other modules. This docking flexibility requires from this module that the angles and distance from the screen can be easily changed. As a result this and considering the financial point of view, a moveable monitor (see Fig.10) instead of a projector was considered. The monitor module can be used to upgrade the other modules with new functions (see Tab.2).

Fig.10. Monitor Module

In combination with the training modules, the Monitor Module guides the user through a virtual form to undertake his/her exercises where the user gets real-

time measurements and feedbacks during training. Another interesting function is the Development Scale. The user can track how their health status improved or worsened during their stay in the hospital. If interested, the patient can also compete against other patients in training competitions. Also, virtual reality is an interesting aspect that can make the training more fascinating. Through the competitions and access to an online patient community network, the elderly have the opportunity to meet and interact with other patients and socialise with them. Additionally, the monitor module can be docked to the eating module. Since the remaining family and friends usually do not live near the hospital, there is the possibility to eat with them via telepresence. The screen is large enough that the patients have the impression of being in the presence of their family. The online patient community can also help the elderly if the patient has questions about his stay at the hospital. Together with the Gaming Module, the Monitor allows playing the games on a bigger surface.

Tab.2. Functions of the Monitor Module

Counselling Service	• Online patient community
Entertainment Service	• Cognitive games • Fine motoric games
Rehabilitation Service	• Virtual physical therapy • Rehabilitation games • Real-time measurements and feedbacks • Development scale
Socializing	• Eating video calls with family, friends • Online patient community • Facebook, Skype

CONCLUSION

Although demographic changes pose some challenges to the future society, it also provides a chance for projects like REACH to find a solution for prolonging the duration of healthy life of the elderly by keeping them active. One important aspect is the continuous monitoring of the health condition of the patient. Therefore, the system can identify unusual patterns and predict probable acute events. Preventive solutions will lead to an improved health condition in the long term, and it will also support the patient and the nursing staff in their daily chores. Since the elderly spend most of their time in bed during their stay at a care facility, a system which could be integrated into the hospital bed was required. From the findings of the research, the concept of a modular system which allows modules with different functions to be integrated with the hospital bed was developed. The system can adapt, and changes can be personalized according to the health level and individual situation of the patient. The different modules cover a broad spectrum of problems faced by the elderly, for example, incontinence, decubitus, sleeping problems, social inclusion etc.

The motivation of a patient to undertake physical activity is a central disturbing factor for the success of the treatments. Daily, the user has to be motivated to use the training equipment. A few elements in this project have been developed for improved motivation, but the intended user should have a positive attitude towards sport. The elderly should also be open to new technologies. Special tests to evaluate the patient's motivation and trust level concerning the developed solution are highly recommended.

In addition, demographic changes in the future should be critically taken into account. Due to such changes, massive pension reductions could be expected in Germany. Presently, poverty among retirees in Germany is of great concern and this phenomena is expected to worsen. Therefore, it is necessary to reduce production and maintenance costs as much as possible so that the elderly can afford the products in future. Further criteria should be explored to develop the business model, for example, bed sharing strategies could be a viable method.

ACKNOWLEDGEMENTS

The design study outlined in this paper was carried out as part of a Master Thesis and used the project REACH as a use case. The chosen setting of a hospital environment required a deep understanding about problems in a hospital. For this the support from members of Schön Klinik in Bad Aibling, especially Mrs. Barbara Schäpers, Mrs. Daniela Becker and Mrs. Irene Grosch who allowed me to interview them was essential. I am grateful to Prof. König for his comments on an earlier version of the Master Thesis. Finally, I want to thank to my advisor Dr.-Ing. Thomas Linner who encouraged to pursue this topic.

REACH: this project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 690425.

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