Silver-Mobility – near field mobility concepts for the age group 50+

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ABSTRACT

The research group "Silver-Mobility - near-field mobility concepts for the age group 50plus" develops concepts to support elder people with beginning or advanced loss of their personal key mobility. Also the improvements of existing systems to substitute loosen abilities like wheel-chairs are in focus of the research group. The paper gives an overview about the approaches and some resulting concepts, mainly for overcoming of obstacles with wheel-based mobility aids, for energy storing solutions and for different assistance systems for mobility aids. The main principle for all these concepts was to get know and analyze the future users, their requirements and needs and then derive solutions from these analyses. The results show the necessity to develop adaptable, individualisable and re-configurable systems.

1. INTRODUCTION AND MOTIVATION

Only those people whose are able to move independently and securely in everyday life will age self-determined and in dignity. It is not so much about covering of long distances, but rather the key-mobility walking, which allows access to all other forms of mobility. It is known that physical and sensory performance of people decreases with increasing age. This process starts at age of 25 years mostly unnoticed, but in the so-called middle-ages (from 50 years upwards) people tangibly lose both muscle force and mass. This disease called sarcopenia is the early beginning of loosening the own mobility [1, 2, 3, 4, 5, 6]. Without any intervention this process can and does lead to both the slow and the sudden loss of the key-mobility. Given by the demographic development the individual problem rises to a social one. Of course, market provides technical assistance and aids, but they are rarely optimally adapted to the user's needs. To identify the vulnerabilities and to design new mobility concepts is a declared goal of research group "Silver-Mobility – near-field mobility concepts for the age group 50plus" as part of the Thuringian Innovation Center for Mobility (THIMO). This contribution can be delivered by the research group, because the project involves technically different reported staff in interdisciplinary work, in the span of healthcare professionals and engineers from various sources to economists, who are situated at the Technische Universität Ilmenau, Universitätsklinikum Jena and the Fraunhofer AST Ilmenau.

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2. APPROACHES

Based on analyses of market and user requirements vulnerabilities were identified, which cannot be concentrated in one area, but relate to several areas of work, as shown in Fig 1.

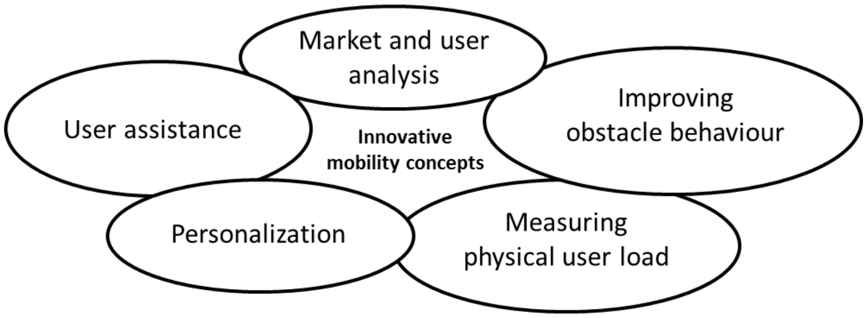


Fig. 1: From the preliminary analysis derived fields of work

In each of these areas of work, there are solutions that are systematically tracked and transferred at the end in total concepts.

3. RESULTS

3.1 User's Needs as Basis for Innovative Mobility Concepts

The market research has shown that there is a wide range of different systems for supporting individual mobility. However, the requirement analysis has shown that this wide range does not completely meet existing user needs and moreover overextends potential users. This is surprising, as our studies with users have shown that an individual's mobility plays a crucial role in the life of the generation 50+. Nevertheless, an early involvement with systems for preserving their own mobility does not take place. If acute mobility restrictions are arising, proven mobility aid systems, despite deficits, are preferred while innovative mobility aid systems are attended with acceptance problems. In order to overcome these acceptance problems and initiate an early involvement with mobility aid systems, several studies have been conducted to identify potential user's problems with existing mobility aid systems and requirements concerning future ones.

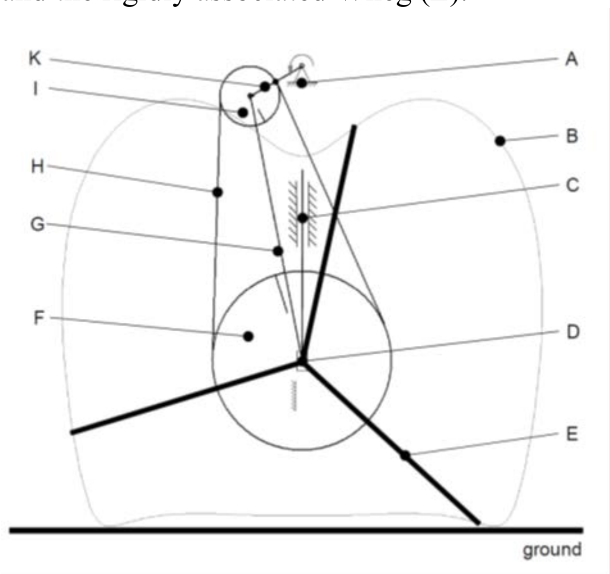
In the first study eight expert interviews and eight interviews with mobility aid users were conducted. The results show that mobility aid users are mostly constrained to their near field. Problems mostly occur in terms of the mobility aid's handling, its safety, its stability, the physical fitness of the user but also the condition of the urban environment, e. g. stairs, curbsides or road metal. These stated problems reveal first insights where existing mobility aid systems need to be improved. However, in order to develop and design innovative mobility aid systems a second study was conducted comprising two focus groups with potential users namely subjects from the generation 50+. By this means, future needs and requirements concerning mobility aids could be identified. The two focus groups included 14 participants in total. The results show that the physical appearance of mobility aids is crucial, that is, the design should be modern but unobtrusive simultaneously. The functions of mobility aids need to be reliable and convenient. However, the discussions also show that potential users have an adverse attitude towards mobility aids on the one hand but only general ideas of how mobility aids should look like and function on the other hand. That is why it is difficult to identify and realize concrete innovative mobility aid solutions. In order to overcome this research deficit and to get more detailed insights into potential customer's needs and ideas, further studies may introduce methods like laddering or develop prototypes.

In that way potential user can see and physical test the innovation in order to support imagination and obtain more concrete ideas and statements.
In summary our studies have shown that a slow pre-accession with the possibility of innovative mobility aid systems can help to reduce barriers of acceptance. Furthermore, innovative mobility aid systems should primarily be reliable, convenient and unobtrusive while overcoming urban barriers. The conducted studies provide a foundation for developing innovative mobility aid systems. However, further research is needed in order to specify requirements concerning innovative mobility aid systems.

3.2 Concepts for improved obstacle behavior

3.2.1 Using the concept of whegs

A promising idea is to use whegs, known from mobile robotics, for transportation of passengers. This demand, however, urges to reduce or in the best case eliminates the dynamic height offset occurring in wheg-driven mechanisms, called alternation. If we succeed in minimizing alternation, an easily implementable and safely usable mobility system could be provided, with a feeling like riding on wheels, able to overcome small steps without having to worry about a possible 'stuck' or ruining the mobility aid.
For this purpose, the principle published in [7], which requires only a single drive for the forward and the up- and downward movement, was taken up and optimized according to the requirements. Considering the region of the path of the contact point (B) between the touchdown and lift-off of the contact point, the maximum possible smoothing was worked out through simulations, compare fig. 2. As the result, this led to a reduction of alternation to 91.6%, based upon the following structural design, shown in fig. 3. The impellent engages on the crank (K) bedded in the crankshaft bearing (A) on which a timing belt pulley (I) is mounted rigidly on which again a timing belt (H) is running, whereby the rotary movement is transferred to a further timing belt pulley (F) with the z-fold (z = number of spokes) diameter. The axes of the gearbox are connected with a couple (G) which converts the rotary motion into a translatory motion of the linear bearing (C) and thus the rotational axis of the Wheg (D) and the rigidly associated Wheg (E).



A = crankshaft bearing
B = path of the contact point
C = linear bearing
D = rotational axis of the wheg
E = wheg
F = timing belt pulley (at the output of the gearbox with diameter $d_2 = z \cdot d_1$)
G = couple
H = timing belt
I = timing belt pulley (at the input of the gearbox with diameter d_1)
K = crank

I and K in rigid coupling

Fig. 2: Technical principle of the coupling between the forward and the up and down movement

3.2.2 Phase-shifting double-wheg-module

Another concept to use whegs in mobility aids by simultaneously utilization of obstacle overcome and low alternation is to increase temporally the amount of spokes. An example for this concept is a phase-shifting double-wheg module. This module consists of a common wheg with four spokes; which is rigidly attached to a shaft (outer wheg). Around this first shaft a hallow axle turns a second wheg (inner wheg) which also features four spokes. Each shaft is driven by a distinct actuator. Due to the use of two motors both whegs are able to turn independently of each other. Using PI control and two magnetic rotary encoders enable a smooth setting of a phase difference between inner and outer wheg. Therefore the amount of spokes of the double wheg-module is changeable: It features eight spokes when travelling over flat terrain (45° phase shift) and four spokes when dealing with obstacles (0° phase shift). Fig. 3 shows the technical principle (left) and the resulting construction (right).

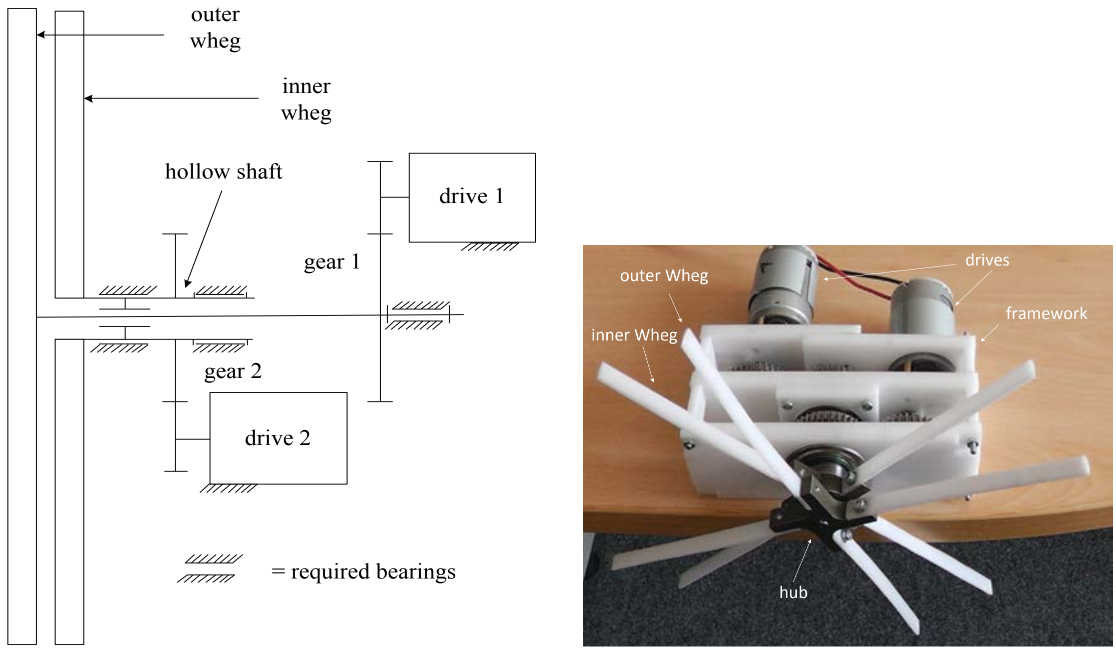


Fig. 3: Technical principle and design of a phase shifting wheg-module

3.3 Personalization of the human interface using the example seating device

Due to diseases and/or normal effects of aging more and more users are forced to spend most of the time in the seated position. Therefore an individual adjusted design of the seat cushion obviates decubitus ulcer and increases comfort as well as safety. Depending on the degree of immobility the seat and the backrest need to be designed to prevent from pressure peaks and sometimes support the person's posture.

In order to achieve an individual cushion for each person there are certain process steps that need to be performed. The current method is to cast the user`s body with an special vacuum molding seat that secures the shape of the body. Afterwards this shape is measured by a tactile system that creates a digital surface in order to get the necessary data for the milling process.

The process of reproducing the shape of the moulding seat is very time consuming. Therefore this should be replaced by a more time-efficient method like an optical system that can produce more data.

There are three basically ways of producing three dimensional data with an optical system: stereoscopic vision, structured light and the detecting the time of flight method. The stereoscopic method requires two cameras that are aligned to each other in a certain distance and angle. The two images taken from the cameras will be compared in order to generate the

3D data. Another common method to measure 3D surfaces is the triangulation. Therefore a certain pattern is projected on the object and the reflected image will be detected. The characteristics of the pattern are well-known as well as the distance and the angle between the camera and the projector. The comparison of the projected reference pattern and the detected one contains the required information of the surface. The time of flight method reconstructs the 3D data from the lag of time, the light needs to be captured after it has been reflected. Laser light is being sent to the object, reflected and detected from a special kind of camera. Each pixel contains not only the value of intensity but also the time when the intensity was captured. This time difference is used to reconstruct the surface.

The method that has been chosen is the triangulation since this was the most suitable method for this requirement. After the 3D data is been captured and reconstructed, it will be used to process the individualized cushion.

The whole process of measuring the individual shape and producing a customized cushion is a highly complicated and expensive procedure. An alternate way of optimizing a cushion can be realized by optimizing only certain parts of the seat instead of processing a whole new seat. This can be realized by using a modular concept of different cushion materials. The use of a dynamically wheel chair with a skeleton of motorized elements can adapt itself to the person while sitting in the wheel chair [8].

The optimal solution would be combine an adjustable chair with a set of sensors that is able to measure crucial parameter related to decubitus ulcer like pressure, temperature or humidity in order to react and change the posture. In the Department of Mechanism Technology of the TU Ilmenau an adaptive support device [9] has been developed which could be used for this task in further projects.

3.4 User assistance via SAM box

Assistance systems are popular in the automotive industry. They support the driver with security and convenience features to prevent accidents and reduce their consequences. But in mobility aids the use of such systems is rather unusual.

To extend existing electrical mobility aids with additional assistance systems, extensive interventions in the existing control system are necessary. For this purpose, detailed knowledge of the internal workings of the individual components and their interaction are necessary. To simplify the development of new assistance systems, the "Smart Assisted Mobility" technology was developed as a low-cost rapid-prototyping tool. The main component of this technology is the so called “SAM-box”, see figure 4. This module can be integrated with minimal effort in existing mobility aids and allows access to the vehicle-specific internal communication bus without affecting its operation. The SAM box is developed to perform assistance and prediction systems capable of using Matlab®/Simulink® and at the same time to interact with the mobility aid. So it is possible e. g. to integrate additional sensors like the battery status or environmental detection. Similarly, the recording and evaluation of various vital parameters is possible in order to monitor the current user state.

Fig. 4: SAM Boxes. The opened case shows an additional prototyping area.

The SAM-Box consists of two separated modules. The main task of the first module is to realize the CAN real-time communication to the vehicle specific communication bus. This module is based on a microcontroller system with a cooperative multitasking. Furthermore, it contains eight analogical and digital in- and output ports as interface for additional sensors and it provides the power for the second module. The second module is a BeagleBoard-xM. This Board is used for data processing and control. In addition it offers 4 USB connections and a network interface. So a wide range of different sensors are able to use with the system. It communicates with the first module by using a UART interface with a data rate of 100 Hz
The software of the system consists of three separated software parts. The first part is the firmware for the real-time communication to the vehicle bus. It is designed to tunnel or to manipulate the data from the vehicle input device to the power output stage. The second part is the operating system on the BeagleBoard-xM. Here an embedded Linux (3.12.6-rt Kernel) is used with a simplified Ubuntu system. This is needed to enable the usage of open-source libraries for a faster development of assistance functions. The third part is the algorithm of the assistance system and runs as a rt-task on the BeagleBoard. The development occurs in MATLAB/ Simulink. Therefore library components for in- and output of the communication bus were developed to simplify the research of assistance systems. Now algorithms verified in simulation can be tested in real world.
By using the libraries and the hardware interfaces new hard- and/or software modules can be integrated in the mobility aid for research and testing with users, see figure 5.

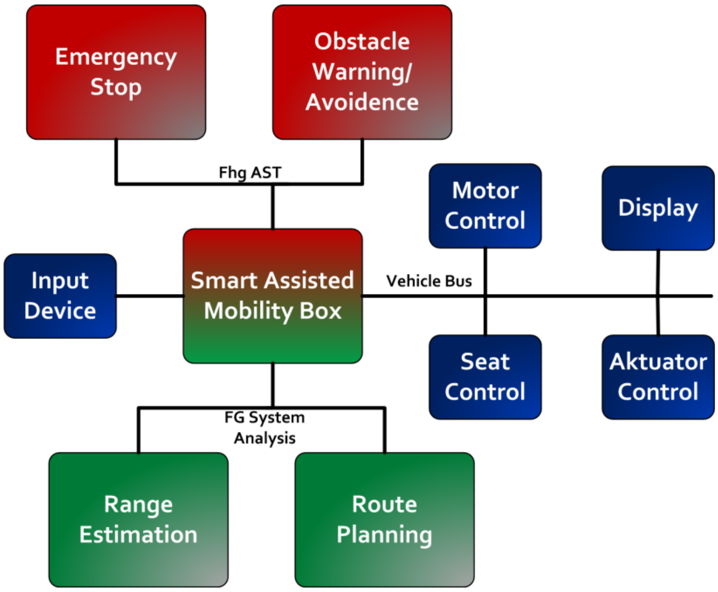


Fig. 5: Structure of modular extended control system of mobility aid

As one of the work packages of the research group Silver-Mobility assistance systems for range estimation and obstacle avoidance for powered wheelchairs are currently being developed. Assistance systems, which are adaptable to the respective performance of the user (e. g. support drives for wheelchairs) are also conceivable.

3.5 Development of a test bed for mobility aids, measurement of the physical user load

In general, the technical test of mobility systems is carried out by the manufacturer or external test facilities. It is focused on functional technical parameters and fatigue strength. But the interaction between the user and the mobility system is usually not part of the test procedure. Furthermore, today's mobility aids are little customizable to the individual user. The physiological and psychological characteristics of the users should be considered for the creation of mobility systems. A mobility aid should support and encourage the user's mobility, rather than replacing it. Thus, e.g., the level of support could be regulated individually to the current state of need and accordingly to the terms of use. From a medical perspective this makes a major contribution to the physical and mental/cognitive health. [10]
For this purpose, a multifunctional test bed was designed to examine the interaction of the user and an individualized mobility aid under repeatable conditions of measurement. It should be possible to model various real usage conditions. As measuring goals, the effects of shock and vibration, the influence of slope and lateral gradients, as well as the collection and analysis of vital parameters, such as heart rate and myoelectric parameters, were defined. In addition, psychological variables could be collected.
The needed test environment of the mobility system and its user could be provided by a test bed, as it is presented as a concept design in figure 6. It consists of a frame, height adjustable wheels, an actuated treadmill belt with optional obstacles, an entering support and safety equipment. The belt is formed by laminate from layers of polyurethane and metal meshwork. The dimensions are 2.40 m x 3.50 m, and the belt is equipped with integrated connectors for different obstacles. These obstacles with a maximum height up to 5 cm are used to excite vibrations and/or shocks onto the mobility system. The maximal excitable vibrations frequency is about 30 Hz. The belt, driven by a three-phase motor with a moment of 1000 Nm, slides over a massive steel plate, which supports the weight of the mobility aid and the user.

The inclination of the belt can be adjusted between -15 % and +15 % in steps of 0.05 % in two axes, to simulate up- and downhill movements as well as hillside cross rides.
For security reasons, a cage is installed around the test bed with hooks to safeguard the mobility system, and also emergency stops are integrated. The test bed was designed for both manual support systems and electrical driven mobility aids.

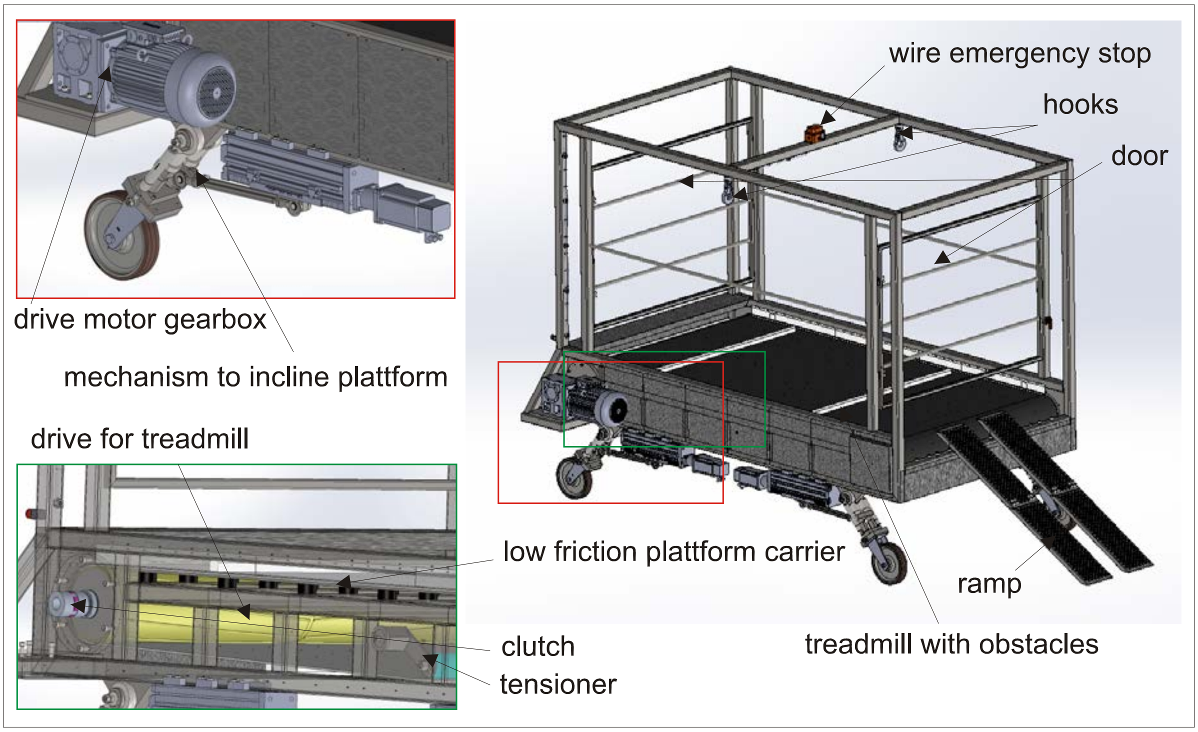


Fig. 6: Design and details of the multifunctional test bed [11]

The described test bed allows simulating the influence of the typical ground parameters, as they can be found in the urban environment of a mobility aid user.
If the user is equipped with, e.g. heart rate, respiratory rate, or surface EMG sensors, it will be possible to generate data, which can be used for the control system of a manual mobility aid with an electrical support drive. The needed initial user data are determined in performance tests at a hand-bike ergometer (see figure 7). Using these parameters, it is possible to estimate the fatigue state of the muscles and to offer the user an individual level of support by an electric drive. Corresponding to the measured parameters the SAM-Box intervenes into the drive regulation. A typical sign of muscle fatigue in surface EMG´s (sEMG´s) is both the increase in the root mean square (RMS) and the decrease of frequency.

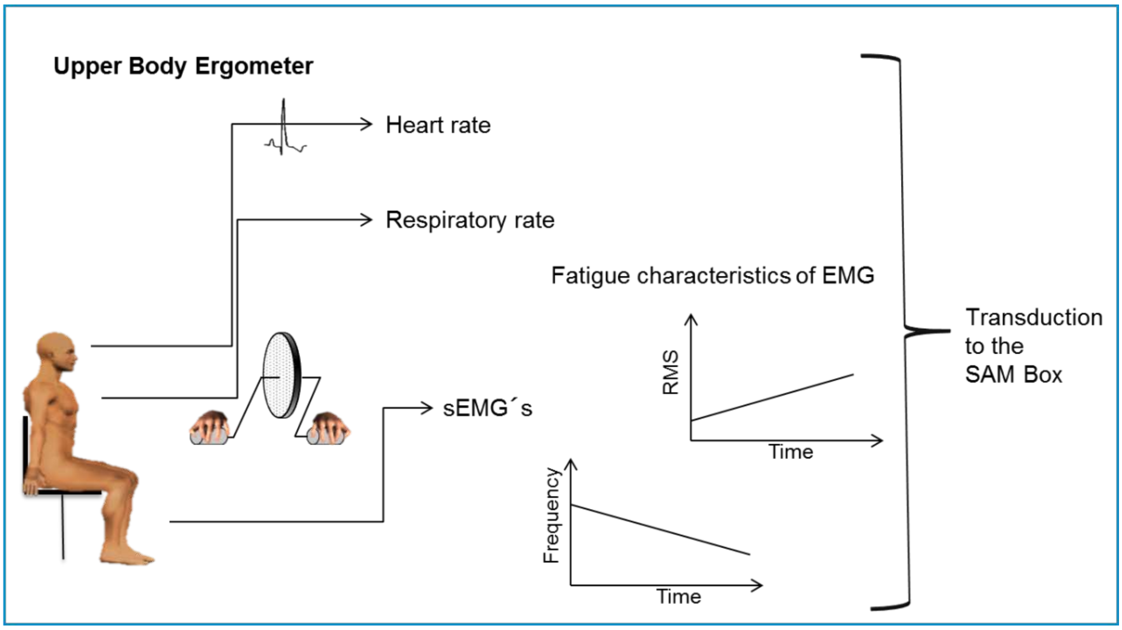


Fig. 7: Upper Body Ergometer, recording and transduction of vital parameter as initial parameters for the SAM-Box

3.6 Storing of energy for mobility solutions

3.6.1 Purpose

Near field mobility systems address people of an aging society to ensure active individual locomotion up to a higher age. In general the independent strength and mobility will decrease with increasing age. Balancing this loss can be achieved only by the use of aids. Younger people will require only an aid that converts human power and energy with high efficiency (e. g. bicycle). Elder people may require additional components to supply additional energy. Such a mobility system equipped with additional energy storage has to fulfil special requirements, like high usability, an interface to reload the energy storage, a low mass and an environmental friendly way of using, which means minimal noise and exhaust emissions. The emission of fumes needs to be avoided especially in public indoor areas.

The support level of the system should meet the individual requirements. Therefore energy storages are suitable, with a controllable output. Furthermore the overall mass should not be increased significantly. The mass of an energy storage compared to the stored energy is expressed by the term gravimetric energy density. Portability of the whole system can only be provided by a compact and light storage solution. Additionally it should be possible to reload the storage on external charging station in an urban environment.

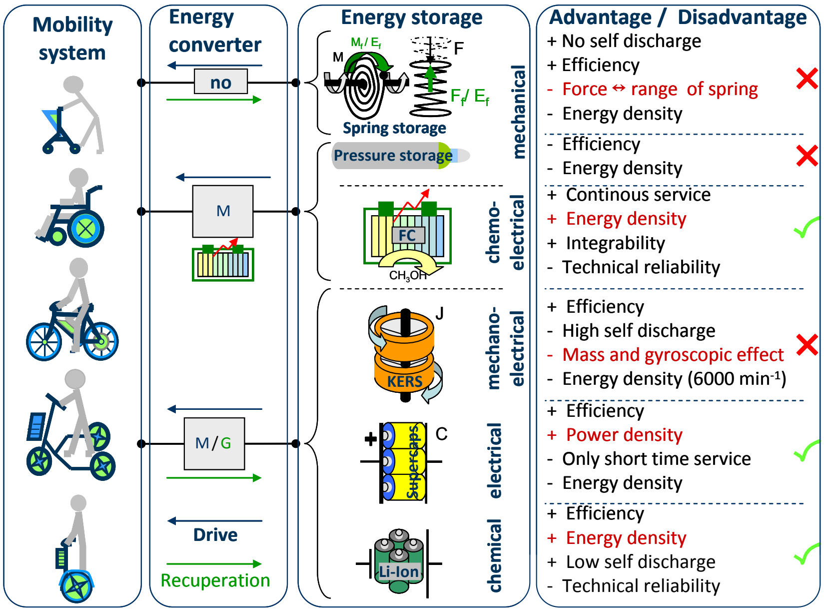


Fig. 8: Concepts of drives and energy storage systems for mobility aids

3.6.2 Energy and efficiency

Energy is described as the ability of a closed system to do work. In theory, mechanical, electrical, chemical, thermal, and nuclear energy are technically useable, but only a few of them are usable in near field transportation. Each energy transformation comes with energy losses; most of all appears warmth when energy is buffered or stored. Therefore energy efficient storages need to be considered. Efficiency is the relation between energy that is added to a system and the finally usable energy.

Electrical energy is one of the most universal, technical usable and convertible forms of energy. Most of all it is stored in an electro-chemical state which means batteries (primary cells) or accumulators (secondary cells). Figure 8 shows within others mechanical energy storages. Their possibility for adoption to a particular support level of a mobility aid is limited by their supply characteristics. Due to the mass of the storage and additional components for transformation, a reliable ratio between mass and usable energy content cannot be formed.

3.6.3 Electrical energy storage and converter

Electrical energy can be used widely and is storable either direct in electrical or indirect in chemical or chemo-electrical form. Furthermore some details of supercaps and fuel cells seem to be very interesting to meet the requirements of novel near field mobility systems.

On the one hand, new standards for energy density in mobile systems have been established by lithium-based secondary cells. On the other hand, exact matching load and unload currents, which are only achievable by the use of additional battery electronics and battery status supervision, are required by the technology. Electricity is almost everywhere available in a usual neighbourhood, which allows a simple recharging during the trip. Li-Ion accumulators are rechargeable up to 80 % of their nominal capacity within short time and allow inter-mediate but incomplete recharging at any time.

Supercaps are advanced capacitors with higher capacity and power density. Electro-chemical material transport is not required to store energy, which allows a considerably faster charging process than electro-chemical systems. In comparison to electro-chemical energy storages it has a lower energy density. Therefore hybrid structures have been developed. In such systems, the first electrode acts as electro-static double layer capacitor the other is an electro-chemical element and works like an accumulator [12, 13]. An independent application as

energy storage for near field mobility solution cannot be recommended because of its low energy density. Only in combination with state of the art accumulators they are useable.
The fuel cell is not an energy storage for its own, but provides electrical energy because of the so-called effect of "cold burning". Hydrogen serves as primary energy carrier and will be divided at the anode into ions and electrons. Finally it recombines in an oxidation reaction at the cathode into water. The electrolyte is permeable for protons but impermeable for electrons and divides the electrodes. The electrons are guided through a separated circuit where a load can be connected. For the use in a near field mobility system low temperature polymer electrolyte membrane fuel cells (PEMFC) are suitable. Hydrogen can be stored only under difficult circumstances. Pressure or cryo (very low temperature) storages increase the system mass and therefore decrease the gravimetric energy balance. Alternatively fuel cells exist that work with liquid methanol - the direct methanol fuel cells (DMFC). DMFC produce the required hydrogen directly by a catalytic process at the electrode. An electro-chemical oxidation of methanol takes place at the electrode [14]. Methanol (CH3OH) as an energy carrier provides a simple and fast recharging and refuelling, but the efficiency and lifetime of DMFCs are reduced. As a product of the whole chemical reaction the DMFC emits carbon dioxide. All fuel cells are silent and almost without emissions. Another advantage is their scalability to meet the requirements of any mobility system according to power and energy consumption.
It can be concluded that electro-chemical energy storages meet best the requirements of near field mobility systems. Wide experience, standards, high energy density and scalability are featured by Li-ion accumulators.

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