Co-funded by the Horizon 2020
Framework Programme of the European Union

REACH

Deliverable D15: PSS concepts based on motivational strategies (associated with tasks T4.2 and T4.3)

Abstract: The overall goal of REACH is to promote physical activity and reduce the risk of functional loss amongst elderly through early detection and intervention. This deliverable report presents the first key concepts created and developed in the REACH project, that are amongst other things based on the principles of behavior change. Due to the partners involved this deliverable focuses on **Touchpoints 1 and 2**. Other Touchpoints will be developed further as part of other task in **WP4**.

In this deliverable five major contribution to that goal are presented: (1) Application of relevant motivational strategies to the **Touchpoint 1** and **2**, (2) Intervention Product Service System Concept, complemented with early detection, (3) schematic design of modular adds on to **PI^{2}U** (bed and stander), (4) schematic design of **PI^{2}U**s multifunctional personal mobility system (activLife) complemented with first prototype testing results, (5) functioning of the identified intervention strategies in the context of REACH engine, complimented with application scenarios.

This deliverable details interventions, touchpoints, that apply knowledge on behavior change that has been described in **D4** and **D14**. Furthermore, it includes and where possible adopts the sensor technology that has been or will be developed as part of **WP2** for sensing and monitoring behavior and health status. By also including algorithm and data technology developed in **WP3**, we ensure that REACH can make full feedback loop on intervention, behavior change, measurement, interpretation and updated intervention. This deliverable not only aims to describe the interventions that were developed for Touchpoint 1 (Personal Mobility Device) and 2 (Active Environment). We describe initial (pilot) tests, as well as reflect on how effective the application of the behavior change strategies has been in those Touchpoints. As we consider this to be an iterative process, this reflection is essential for further optimizing the impact these Touchpoints, and REACH as a whole, can make in the domain of seniors, health, and activity promotion. The current deliverable (**D15**) is associated with **T4.2** and **T4.3**, both residing in **WP4**. The premise of these tasks, and the deliverable, is to investigate applicable motivational strategies and to create an intervention based on sensing, monitoring and personal mobility device. The deliverable will also suggest and illustrate where possible, how to apply the interventions in the REACH Touchpoints 1 and 2, defined in **D4**.

This deliverable outputs are relevant for working on the development of the PSS (Product-Service System) concept. Only a combination of motivation strategies, accurate sensing and monitoring system and personal mobility device adjusted for the user needs will create the proper intervention which can be applied for the older adults with decreasing life activity to prevent further decline and other adverse outcomes such as falls and disability which is the main goal for the REACH project.

Since the current deliverable (**D15**) reports on ongoing tasks (**T4.2** and **T4.3**: M15-M36), it will be updated in accordance with the progress of work in these tasks.

Lead Partner:	AM
Participants:	TUM; Philips; Tu/e; HUG; AH
Document Identifier:	REACH Deliverable D15
Version (Date):	1.0 (23.10.2017)
Due Date:	31.10.2017
Linked WPs/Tasks:	WP4/T4.2, T4.3
Type:	Public
Authors:	Ilona Owusu, Carlijn Valk, Lu Yuan, Jörg Guettler, Amir Kabouteh, Dominika Kozak, Dawid Jankowski, Mirana Randriambelonoro, Thomas Visser, Rongbo Hu, Hans Lingegård

Date	Activity	Status
28.07.2017	Deliverable strategy ready	completed
10.08.2017	Deliverable structure ready	completed
15.09.2017	Input of participants/partners ready	completed
16.10.2017	Input integrated and formalized	completed
23.10.2017	Draft of report ready	completed
29.10.2017	Review completed	completed
30.10.2017	Submission to EU	completed

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Abbreviations for partners:

AH: ArjoHuntleigh
AM: Alreh Medical
CU: University of Copenhagen
DTU: Technical University of Denmark
EPFL: École Polytechnique Fédérale of Lausanne, Switzerland
HUG: Hôpitaux Universitaires Genève
PSS: Product Service System
SC: SmartCardia
SK: Schön Klinik
TU/e: Eindhoven University of Technology
TUM: Technical University of Munich
ZZ: ZuidZorg

D: Deliverable report.

Decomposition of testing approach: For each Touchpoint separate testing parts/instances (early detection, motivational techniques, and programmed interventions) were created and each of this testing instances represents a separate trial with an own hypothesis, own outcome measures, and an instance specific trial design.

Early testing: small user feedback and iteration loops to develop qualitative features

Engine: The “Engine” – in itself also modular with regard to its functionality – serves from the viewpoint of the end user as “invisible” back end system. In general the end users (elderly) are supposed to interact with the “engine” primarily in an indirect way through the Touchpoints.

Integration activities: cover in REACH both the integration of parts and components to Touchpoints and the Engine (systems) as well as the integration of selected Touchpoints with each other and the Engine (to a system of systems) for certain verification/validation test scenarios.

Interface specifications: besides the system architecture, and the design of individual components or systems, interfaces play a key role in guaranteeing cross-compatibility.

Interfaces: A key aspect in that context is the identification and analysis of interfaces. Interfaces state ways of communication between system elements. According to Langford in systems, individual elements can interact and interface in terms of four, basic ways: Energy, Matter, Material wealth and Information (“EMMI”). In Deliverable D4 (Section 5.5) three types of interfaces have been identified a key for REACH: system-system interfaces, human-system interfaces, and B2B interfaces.

Modularization: as defined for example by can be considered as means to control the internal complexity of a system e.g. by reducing and clarifying the interfaces between system elements.

Sensing and data analytics process specifications: In REACH test with various types of sensors will be conducted in a variety of use case settings in different countries and under the control of different study leaders. In order to be able to exploit the resulting data sets efficiently by using data analytics algorithms, these data sets and the process of creating them must follow certain specifications.

System architecture specifications: High-level system architecture specifications were set up in Deliverable T1.4/D4 (Chapter 5) clarifying the relations, interfaces, and the modular structure of the individual Touchpoints and their sub-systems and components with the Engine and the use cases to which.

System architecture: The structure of the overall system of systems is expressed by the REACH system architecture (following the terminology of the standard ISO/IEC/IEEE 42010:2011, see Chapter 5/ Deliverable D4) which decomposes the system, and defines links and information flows between the individual parts of the system and with the environment (stakeholders, use case settings, etc.).

Systems engineering: Langford (2012) characterizes systems engineering as the preparation of individual system elements for integration. System integration can efficiently be accomplished in a continuous, step by step manner (see, for example, the Continuous Integration Model as outlined by in which iteratively first selected components are integrated before subsequently larger sets of components are integrated in order to reduce the complexity of the integration process.

T: Task defined in the project proposal.

Touchpoints/Engine concept: structures the envisioned REACH product-service-system architecture, into manageable research and development clusters.

Touchpoints: The "Touchpoints" will act as "graspable" front end towards the end users (elderly). The Touchpoints will serve as data gathering devices as well as mediator of services and interventions coordinated by the Engine towards the end user. Each Touchpoint is modular and made up of several subsystems which allow to adapt the system both for a certain person or setting as well as over time.

Use case setting: Use case setting refers to the four solution operators and this report

WP: Work package defined in the project proposal.

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1 Background and summary of tasks and activities related to D15/T 4.2

1.1 Introduction (Touchpoint engine concept)

Stating a key achievement of the first project year, the REACH consortium has developed and detailed a holistic conceptual solution, the "**Touchpoints and Engine concept**" (**Figure 1-1**), based on an in-depth analysis of the four REACH use case settings, and the identification and inclusion of consortium internal and consortium external stakeholders (elderly, care personnel, insurances, etc.) in the system architecture development process. This conceptual solution fully reflects REACH's "Product-Service-System" value proposition. 5 physical touchpoints will function each as data gathering and intervention devices, which are bound together by cross-sectional, integrated engine (i.e. platform) functionality.

Touchpoints 1-4 not only state development an innovation clusters within the consortium, but:
represent each a specific dimension of physical activity in general (REACH Physical Activity Dimensions, PADs),
and will each implement an instantiation REACH's unique Sensing-Monitoring-Intervention Activity Flow

Touchpoint 5 and the Engine state cross sectional development areas that serve these 4 PADs. A detailed description of the Touchpoint and Engine concept and the REACH partners and use case settings associated with each of its components are outlined in detail in **deliverable report T1.4/D4**.

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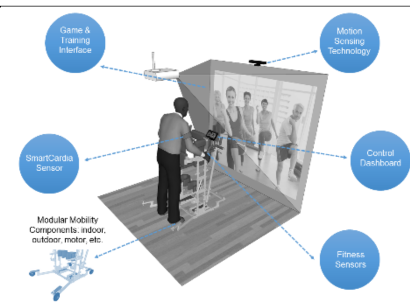
<tr>
<td>Touchpoint 1:
Personal Mobility Device

PAD 1: macro mobility, general physical mobility in house and neighborhood</td>
<td>
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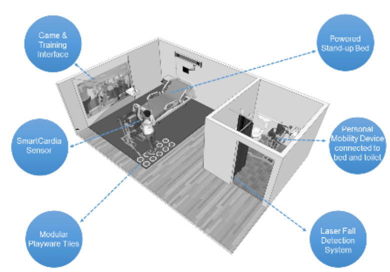
<td>Touchpoint 2:
Active Environment

PAD 2: micro-mobility, postures, and ADL execution</td>
<td>
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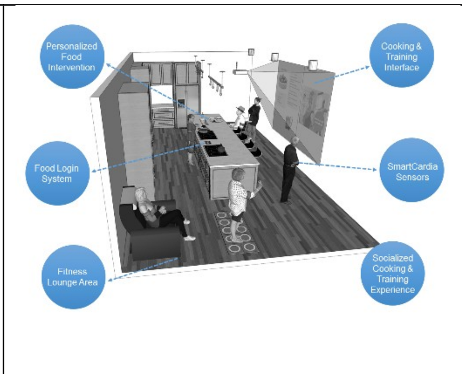
Socializing & Nutritional Monitoring + Intervention

PAD 3: nutritional monitoring and intervention in the context of physical activity, fictional ability, and socializing</td><td>
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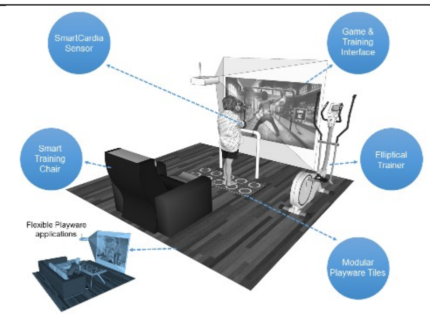
<tr><td>Touchpoint 4:
Gaming & Training

PAD4: gaming and training</td><td>
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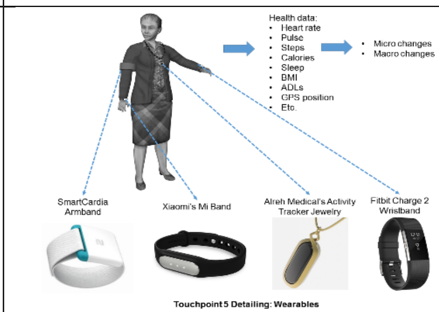
<tr><td>Touchpoint 5:
Wearables</td><td>
</td></tr>
</table>

Figure 1-1: Touchpoints not only state development an innovation clusters within the consortium, but represent each a specific dimension of physical activity in general and will each implement an instantiation REACH's unique Sensing-Monitoring-Intervention Activity Flow

"Touchpoints" will act as "graspable" front end towards the end users (elderly). Touchpoints will mainly materialize as "furniture/PI²Us" in a broader sense, i.e. elements that can be placed and moved within a certain environment or setting (e.g. beds, bath furniture, mobile walkers/standers, large scale interfaces, smart flooring tiles, smart tables, etc.) but also as ambient sensor add-on modules and wearables. The Touchpoints will serve as data gathering devices as well as mediator of services and interventions coordinated by the Engine towards the end user. Each Touchpoint is modular in itself (thus also serving as a kind of physical product platform) and made up of several subsystems which allow to adapt the system both for a certain person or setting as well as over time. The "Engine" ICT platform - in itself also modular with regard to its functionality – serves from the viewpoint of the end user as "invisible" back end system. In general, the end users (elderly) are supposed to interact with the "engine" primarily in an indirect way through the Touchpoint.

In this deliverable we will focus mostly on the **touchpoint 1 and 2** as a basis for the Product Service System (PSS) concept. The main goal of those touchpoints is to maintain the way from hospital (touchpoint 2) back home (touchpoint 1) and enable senior to stay at home for as long as possible in the best condition.

1.2 Relation of WP4 / T4.2 & T4.3 to other WPs

The overall goal of REACH is to promote physical activity and reduce the risk of functional loss amongst elderly through early detection and intervention. This deliverable report presents the first key concepts created and developed in the REACH project, that are amongst other things based on the principles of behavior change, laid out in **D14**.

In particular when considering the promotion of physical activity through technology, interaction and interfaces, it is increasingly important to understand how to keep users engaged, and how to support them in achieving and maintaining change in lifestyle. The specific target group for REACH is seniors, but we hypothesize that principles can be extrapolated to other domains as well, and that, in fact, tackling the application for seniors may prove an even more difficult task, due to usability and accessibility constraints and challenges.

WP4 addresses the intervention regime of REACH. In the Intervention section of REACH, the through the analytics section generated output is used to, to select develop, and or personalize interventions that react on the early detected trends, patterns, or deviations of physical activity with each PAD. In that context sophisticated motivational techniques and engagement strategies are used and tailored towards PADs and individual users and user profiles to create a highly efficient and long lasting behaviour change. In that context WP4 is situated: both programmed interventions and device interventions and interaction in the REACH use case environments are informed, embedded in, and coordinated by the previously by the analytics section identified behaviour change strategy.

Due to the partners involved this deliverable focuses on **Touchpoints 1 and 2**. Other Touchpoints will be developed further as part of other task in **WP4**.

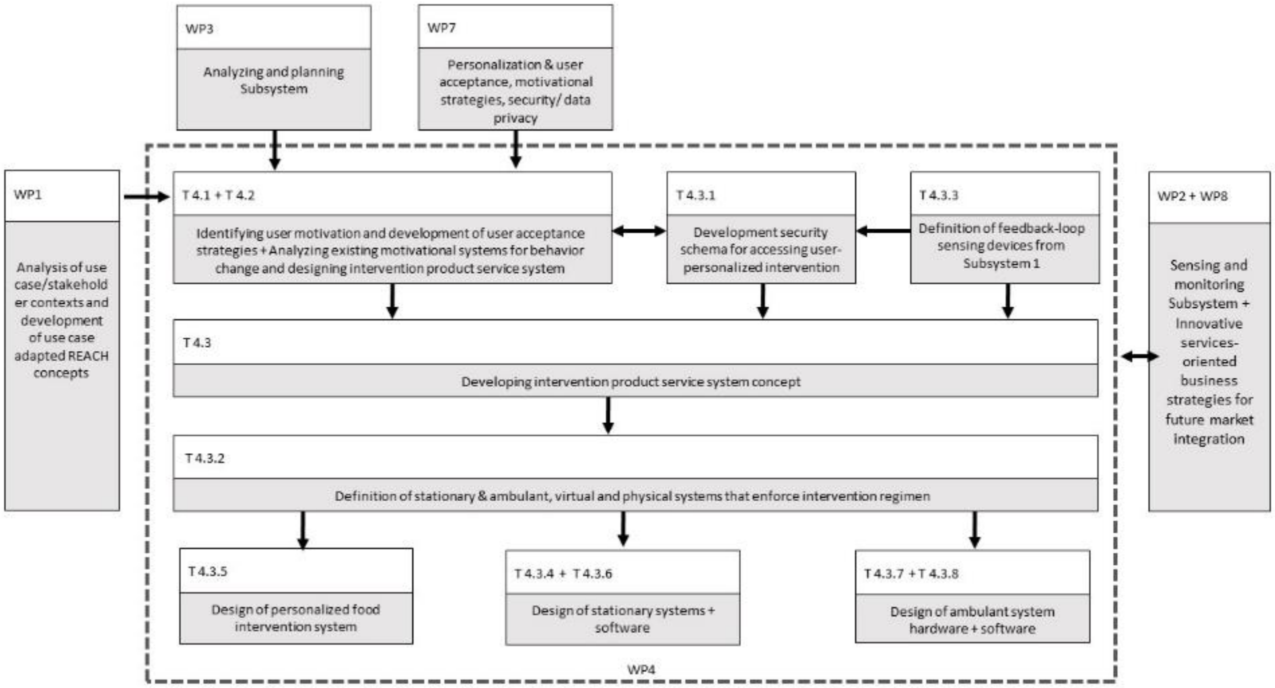


Figure 1-2: Structure of activities developed for WP4

This deliverable details interventions, touchpoints, that apply knowledge on behavior change that has been described in **D4** and **D14**. Furthermore, it includes and where possible adopts the sensor technology that has been or will be developed as part of **WP2** for sensing and monitoring behavior and health status. By also including algorithm and data technology developed in **WP3**, we ensure that REACH can make full feedback loop on intervention, behavior change, measurement, interpretation and updated intervention.

Partners involved in producing of this deliverable, and in **WP4** as a whole, are also heavily invested in **WP6**, **WP7** and **WP8**, ensuring strong connection and integration with the testing of the intervention (6), user acceptance and privacy (7) and business viability of the technology (8).

This deliverable not only aims to describe the interventions that were developed for Touchpoint 1 (Personal Mobility Device) and 2 (Active Environment). We describe initial (pilot) tests, as well as reflect on how effective the application of the behavior change strategies has been in those Touchpoints. As we consider this to be an iterative process, this reflection is essential for further optimizing the impact these Touchpoints, and REACH as a whole, can make in the domain of seniors, health, and activity promotion.

1.3 Motivation for behavior change as a challenge for designing intervention product service system ideas based on a user acceptance.

Behavior change theories:

1. What motivates people for changing their behavior
2. Why it is a challenge/why it is difficult to make the change of behavior
3. How to manage the behavior change
4. Motivation: role of negative and positive approaches

5. How to make a change? Aspects/dimensions of change/motivational approach for change
6. What are the ways for implementing behavior change strategies
7. Pre – intervention and post – intervention behavior change concepts
8. How to affect the behavior change by using the influencers (stakeholders)
9. How to motivate (coaching)
10. **Lasting/sustainable change is only possible to achieve by using the help of influencer**

1.3.1 Barriers to Physical Activity

It is generally known and accepted that physical activity is healthy yet people find it difficult to adopt a healthier, more physically active lifestyle and continue to maintain a sedentary lifestyle. This harmful habit of sitting too much, increases with age, so that the elderly are the most likely to adopt a sedentary lifestyle. Getting seniors to actually adopt a healthier, more active lifestyle is posing a challenge. Just the conviction that physical activity is health, or even the positive belief in health benefits gained from physical activity, does not predict adherence to exercise. It seems satisfaction and enjoyment play a much larger role in motivating seniors to adopt a, or working to maintain a, more active lifestyle (**King, 1998**). Adopting new healthy habits poses other challenges for seniors not just because of the universal difficulty humans have overcoming their aversion to change, but because they face some unique challenges. When considering the barriers to physical activity seniors face, it is also important to consider the barriers seniors perceive to face. These challenges can take the form of attitudinal barriers, physical (health) related barriers, and contextual (related to the environment).

Several studies have examined the barriers that form the obstacles to change toward a more physically active lifestyle for senior citizens. Some of these studies allude to attitudinal barriers such as the unwillingness to prioritise physical activity. Firstly, the information seniors have about physical activity is not sufficient in many cases. Lee et. al. 2008, discusses the misconceptions seniors have abut physical activity; they believe physical activity is irrelevant to their health while they associate any physical activity with physical discomfort and with possible injury. This poor awareness of the benefits of physical activity may be explained by the claim that many seniors lived through a time when these health benefits were not yet known or recognised. Possibly due to the lack of understanding of the important role physical activity plays in overall health and wellbeing, seniors often site that their regular activities of daily living already provide them with ample exercise negating the need for them to increase their physical activity. In a study asking 120 participants, of which 60 elderly and 60 were classified as middle aged, in Kuang, Selangor, Malaysia, about barriers to physical activity, **Justine et. al. 2013**, found that seniors had many barriers in common with middle aged adults. From this study “already active enough” and “do not know how to do it” were the among the most often identified reasons for not participating in physical activity. Both these reasons illustrate the need for better information on this subject. It is possibly due to the lack of information about physical activity that and its importance that, though seniors are known to be the most sedentary population age group, they report themselves as “already active enough”. Besides the lack of understanding of the importance and applicability of physical activity seniors are also often unmotivated to perform physical activity. Seniors also commonly site lack of time and motivation as reasons for not engaging in physical activity. Probably due to the lack of understanding of the importance of physical activity seniors often cite insufficient time as a main barrier to increasing their physical activity. Furthermore, seniors are not always receptive to physical activity promotion messages. **Lee et. al.** found that seniors assume messages promoting physical activity are not targeted at them so that they disregard the message as irrelevant to them. This informational misconception contributes to the difficulties in getting seniors to adopt a more active lifestyle. An improved awareness of the role of physical activity on disease prevention and general health and well-being would be a positive first step to improving adoption of healthy habits among seniors, however for lasting habit change other barriers need to be overcome and other strategies implemented.

For seniors, their physical health or the perception of their physical health can also present barriers to physical activities. In fact, “too tired”, indicating fatigue, was the most commonly cited reason for seniors not to engage in physical activity. Thus, although seniors did not cite “limiting health problem”, “injury”, nor “poor physical conditioning” as the most popular reasons to avoid physical activity it has been found that seniors may assume their physical limitations prevent them from being able to participate in exercise. In addition, seniors perceive the natural physical exertion and symptoms like sweat and heavy breathing as very negative. Anxious about their limitations, seniors with avoid physical activity and especially exercise because they believe it might do more harm than good. It may not be a surprise that seniors see physical limitations as a barrier to physical activity because seniors tend to have lower self-efficacy. This may come from the conviction that their physical health has deteriorated with age irreversibly. It is important to remember that there are opportunities for physical activity for seniors of every level of health and physical ability. The challenge might only be to find activities and exercises that are appropriate for these different levels of ability.

Other studies have been done to look at external or contextual barriers to physical activity. In one such study, in which Canadian seniors took photographs of barriers to walking, **Lockett et. al., 2005**, found that barriers for seniors to engage in this physical activity included a variety of environmental elements. Some of the identified environmental hazards include traffic hazards, such as walking signals not providing sufficient time to cross the street, and falling risks like uneven sidewalks, doors that do not open automatically and a lack of sidewalk. This study also identified that participants saw route proximity to public transport and shops, washroom facilities, enough places to sit for resting along the route and aesthetic qualities as facilitators to walking. Though legislation and city planning could create or improve context for physical activities, such as parks and recreation areas for walking, it might also be beneficial to inform seniors about such locations existing at present and reassure them by providing detailed information about, for example safety and bathroom facilities.

1.3.2 How to Make a Change

Merely informing seniors about the importance of physical activity at any level of physical capability and informing them about suitable walking paths will not result in desired wide-scale adoption of regular physical activity among the elderly. This is because providing this information alone will not motivate the user to change their sedentary behaviour. It has been shown that information or awareness alone will usually not result in the adoption of new or targeted behaviour. In order to affect change the subject, in this case the senior or seniors, have to be addressed with the right message, in the right way and at the right time as described in **Fogg's Behavior Model**. This model describes the importance of the relationship between motivation and ability when designing for behaviour change. **Fogg** describes how when the ability is high (when a task is easy to do) then the subject only needs a little motivation to perform this task. An example of this is buying a packet of gum in the check-out line at the grocery store; it is so easy to add that pack of gum to the grocery belt that one only needs very little motivation, such as liking gum, to purchase this item. On the other hand, this model says that if the ability of the subject is low (when a task is difficult or cost too many resources like time or money which are limited) then motivation needs to be very high to trigger a particular behaviour. Not many people would drive 100 miles for a pack of gum. However, people would and do, achieve very difficult tasks or time-consuming ones every day; as long as they have enough motivation to match. Marathon runners train for months to be able to finish a marathon because their motivation is high enough to overcome the time commitment and sore muscles. **Fogg** gives us a good understanding what is required to activate seniors into moving more; namely that the ability to engage in physical activity should be in balance with their motivation. Suggestions of lowering the engagement threshold to increase the senior's ability would be to make contexts for physical activity such as parks for walks more inviting and providing more information to seniors about the importance of physical activity. However, **Fogg** does not provide a very clear idea about how to increase a senior's motivation to engage in physical activity. According to Fogg's framework, both ability and motivation should be addressed to have the highest chance of successfully engaging the subject in the target behaviour. **Oinas-Kukkonen's** persuasive systems (PSD) provides suggestions on how to support the subject motivation. **Oinas-Kukkonen** describes different strategies which will motivate users to perform the target behaviour through engagement in a designed system. The strategies include *primary task support*, which guides the user in how to perform the target behaviour, *dialogue support*, which motivates the user through engagement with the system, *system credibly support*, which aims to motivate the user through providing information or advise which seems creditable and trustworthy to the user and *social support,* which motivates the user through some form of exposure to what other people are doing. Each of these persuasive design strategies is divided into principles which guide the designer in a more practical way on how to implement these persuasive strategies. For instance, cooperation between users and social learning, allowing users to learn from each other, are two implementable principles which may both contribute to the *social support* which might motivate a user to engage in a target behaviour. **Oinas-Kukkonen's** work provides an overview of options as to how to motivate the user in order to encourage them to pursue a more activity lifestyle. However, as **Foggs** theory states; in order to affect behaviour change, people need to be addressed in the right time, in the right way, with the right message and **Oinas-Kukkonen's** work does not discuss which strategies are most appropriate to use for different people. To this end, persuasive principles should be implemented with care, in order to personalize the approach to the user.

1.3.3 What motivates seniors?

Though every individual is unique and thus what motivates or drives each will differ, research in to motivating seniors to adopt a healthier lifestyle has resulted in some intriguing findings. After conducting a literature investigation into this topic LeRouge et. al. report on the importance of senior's perceived suitability and relevance of an application, in order for the use of it to be adopted. **LeRouge** suggested that the best way to make, for example an application, usable for seniors was to adhere to their mental model of how they assume it should work, in this way tailoring the interaction to the experience and understanding of the senior users. Another study, examining the physical activity of seniors in the Baltimore area found that seniors might respond/ adopt behaviour more readily if advised by a figure of authority. In this study asking 301 people about their physical exercise, it was found that 40% of the people questioned who exercised adopted this behaviour due to their physician's advice (**Burton, 1999**). Further research suggests that, for seniors social contact might be a more valuable motivator than information while enjoyment and satisfaction attained from physical activity is a better indicator for maintaining an active lifestyle. Though these findings are valuable to inspire future work, there is a need for further research in order to discover a clearer connection between the senior user's profile and the strategies that are most appropriate for that user profile.

1.3.4 In order to affect change

The disproportionate ageing of Europe's population poses a wicked problem. It is clear that physical activity will improve the wellbeing of seniors and lighten the burden on care and improving the health and wellbeing of seniors. To address the challenge of stimulating seniors to adopt a more active lifestyle a multi-stake holder approach is necessary. Ensuring effective and lasting behaviour change can only be reliably facilitated with the help of influencers. These influencers might be the public policy and health care agency policy makers in any particular country or might be the care professional or informal family care provider of a senior citizen. These stakeholders can each contribute to the reduction of sedentary seniors in different ways. Public policy makers might facilitate the creation of recreation locations with the specific needs of seniors in mind. Health care professionals could launch champagnes to better inform seniors on the importance of physical activity to their health. Technology offers the opportunity in this context for both early monitoring and detection of medical risk factors as well as the opportunity to provide personalized support and motivation encouraging seniors to engage in and maintain capability appropriate physical activity. This should be done by addressing the senior's personal motivation and considering the senior's physical capabilities and limitations. Further research is necessary to understand with any certainty in what way/ with which strategies this can be achieved. The REACH horizon 2020 project aims to contribute here by investigating technological solutions which support the necessary personalised facilitation of physical activity through a cycle of sensing and monitoring, intervening with motivation and analysing and planning.

2. Application of the motivational strategies to the Touchpoint 1 and Touchpoint 2

2.1 Early detection

As part of work accomplished in **WP6** as system integration approach for REACH was developed following the V-Model approach (**Fig. 2-3**).

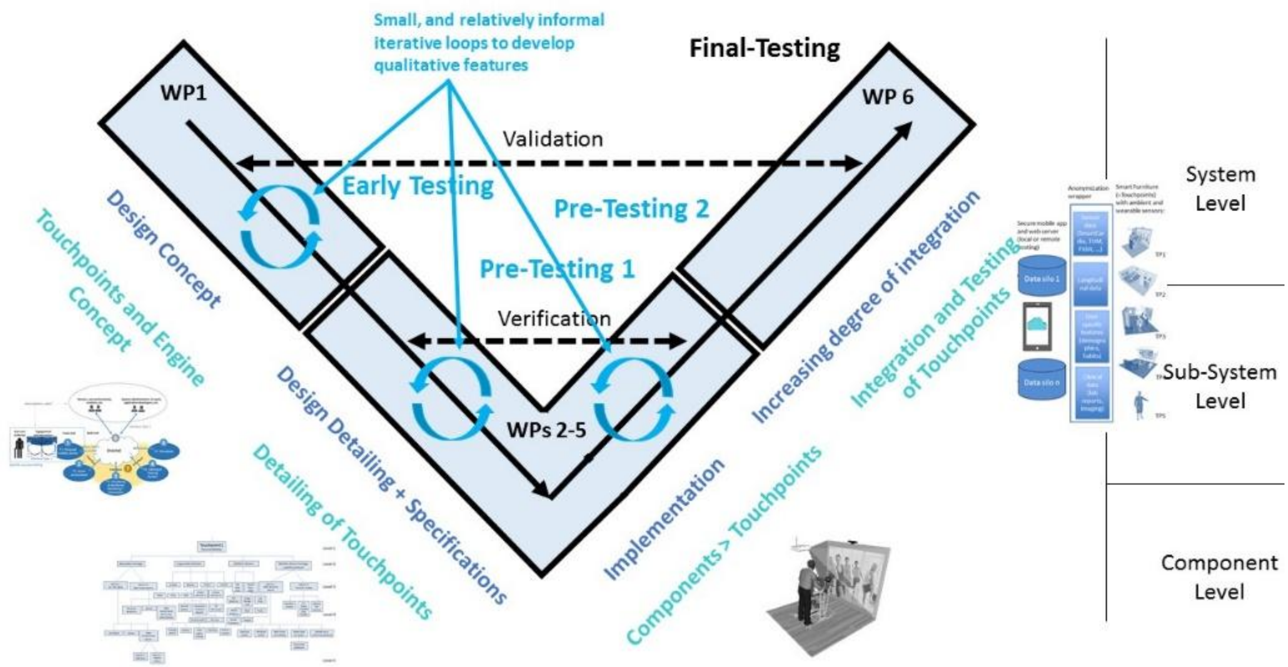


Figure 2-3: REACH flexibly utilizes and combines elements of the (1) V-Model approach, (2) Agile Management, and the (3) NASA systems engineering approach

As part of the **Sensing** section of REACH, physical activity was further detailed as the target condition and categorized into Physical Activity Dimensions (PADs), namely 1) macro-mobility, 2) micro-mobility, 3) socialising and nutrition, and 4) gaming and training. In that context, several early detection regimes were defined such as a) one-off alarm, b) detection of short or long term activities and patterns, c) device integrated automatic early assessment, which can be applied in specific combinations for each PAD.

A key objective of REACH is to utilize in each Touchpoint a combination wearable and ambient sensors in combination with sophisticated analytics methods to detect the onset of physical inactivity and changes in physical activity as early as possible as the basis for effective, personalized interventions that engage the elderly to increase their physical activity.

Early warning and detection dimensions in REACH:

- One-off alarm (e.g. detection of sudden deviations)
- Detection of short term activities and patterns (over minutes and hours)
- Long term patterns (over days and weeks)

Device integrated automatic early assessment (e.g. validation of an interaction or training with Playware tiles as an equivalent to 6-minute walk test)
Early assignment and optimization of personalized interventions

Work in a variety of tasks and WPs (e.g. **WPs 2 and 3**) has brought to light, that the analytics methods (machine learning and clustering algorithms) used by the key analytics partners **Fraunhofer** and **EPFL** unfold their full potential when physiological signals (e.g. heart rate, pulse, etc. – obtained by wearables) are augmented and labelled with the context in which they take place (e.g. activity carried out by a person, and/or posture of a person, etc., obtained by ambient sensors at the time physiological signals were recorded).

Decreasing activity level is a big problem among aging population. Older Adults are more likely to lead sedentary behavior. We can observe a negative feedback loop: fear of physical activity leads to less activity which further increases the sense of fear of falling during an activity.
For this reason it is a challenge to encourage older adults to undertake any physical activity. While planning and designing various intervention strategies in REACH project different strategies are considered to be used to motivate seniors to be more active, as it was described in **Chapter 1.3** of this deliverable.

In tune with the objectives defined in the DoA, REACH will in in the various Touchpoints address different instances of physical activity as the target condition to be early detected. Physical inactivity enhances the risk of, is associated with, and is an indicator for the development of a variety of secondary conditions, such as decline of functional ability, the onset of frailty, the risk of falls, the risk coronary artery disease, diabetes, hypertension, obesity, osteoporosis, and depression.

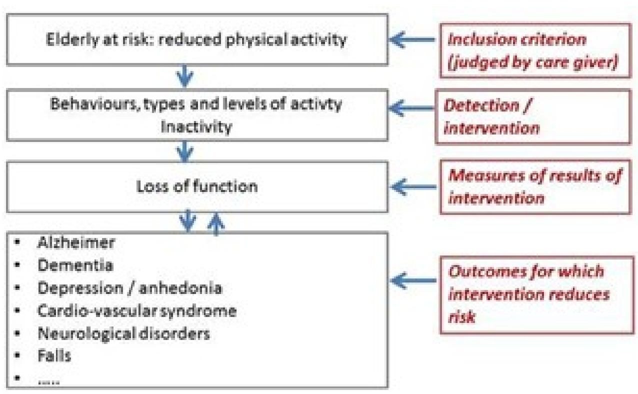


Figure 2-4: Negative feedback loop

A solution by which higher percentage of elderly group switch into higher physical and mental activity against biological and cultural patterns is very difficult to achieve.
A good activation solution must be built on a personal motivation of a senior for change which can be autonomous or (more often) be created in a social interaction.

Frailty is a recognizable health state associated with multi-system deterioration (eg. mobility, cognition, function, endurance) . Not all older adults are frail but it typically impacts the geriatric population. In their study Lawson et al. state that around 10% of people over the age of 65 experience frailty. This number is even bigger (between 25%-

50%) for those over age 85. Persons who experience frailty are more likely to experience adverse events such as falls, hospitalization, disability, dependence, placement in long-term care and death (**Lawson, 2017)** Frailty is also a major risk factor for disability (**Dudzińska-Griszek, 2017)**

According to Dudzińska Griszek, typical physical symptoms of frailty include: exhaustion, weakness (assessment based on the hand grip strength measurement), unintentional weight loss, slow gait and decreased physical activity. The degree of frailty is assessed with clinical frailty scale presented on **Figure 2-5**. Based on the severity of the clinical symptoms of frailty and patient condition **Lawson** present nine different stages of aging from very fit to terminally ill.

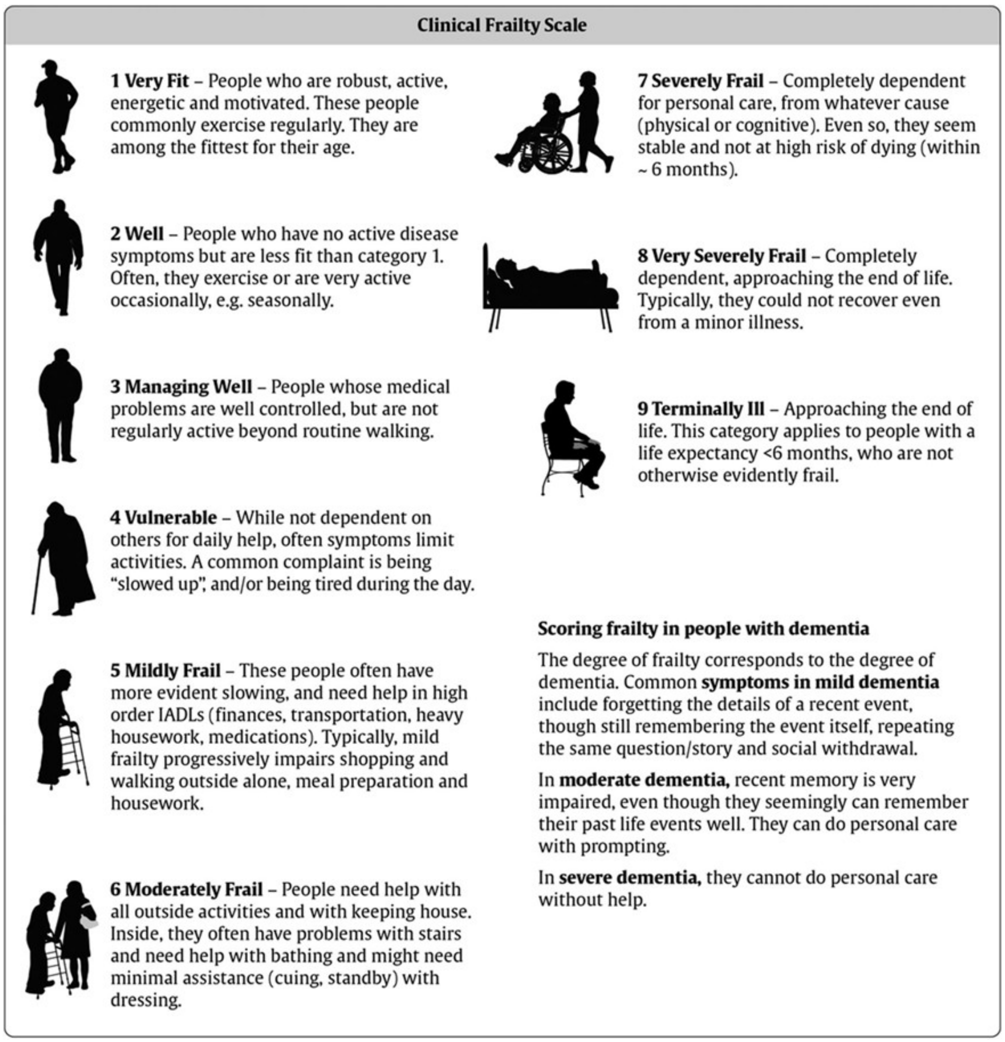


Figure 2-5: Clinical Frailty Scale (Lawson, 2017)

Decreased muscle strength measured by grip-strength, has been associated with an increased risk of all-cause mortality. Weak hand grip strength in later life is a risk factor for disability, morbidity and mortality and frailty.Therefore grip strength is considered a quick, easy and inexpensive method to assess seniors strength (**Dudzińska-Griszek, 2017)**.

Disability in ADL (Activities of Daily Living), which are the essential activities for independent functioning of a person is a negative impact of frailty. Frail elderly people are in a higher risk of ADL disability than non-frail older adults. Effective interventions with focus on disability prevention can reduce the burden caused by frailty. For the development of such interventions it is important to know by which factors frailty-related ADL disability is being predict (**Vermeulen, 2011**).

Falls are the most common cause of f injuries among adults aged 65 years old and older (older adults) which might be fatal or non-fatal. “Indoor falls” are given more research attention than to falls that occurs outdoor. Those who fall outdoors are considered to be healthier and more fit than those who fall indoors (**Satariano, 2017).** The typical faller profile described in current literature are frail older adults who commonly fall indoors and healthy older adults who fall outdoor mostly.

The primary causes of falls are age-related deterioration of postural stability in combination with impaired mobility, gait and balance (**Morrison, 2013)**.

Frail seniors under the risk of falling are often afraid to spend time outdoors. When they spend more time indoor they are more likely to fall there. Researchers suggest that preventive strategies to improve mobility and balance are not sufficient for all older adults. Those who are walking outside need special attention to address the prevention strategy in the best moment (**Satariano, 2017).** More detailed information on location, timing and conditions of falls and about person’s daily activities and movement is needed to achieve the goal. The monitoring and comparison of the mobility level of older adults is crucial to learn about the timing, location and circumstances of regular activities performed by older adults. This assessment provides useful information about falls which occurs both outdoor and indoor as a part of everyday life (**Satariano, 2017).**

Falling among elderly persons can lead to hospitalizations, disability and premature death. It may also result in a psychological trauma called fear of falling. Such fear may lead to self-restriction of activities and staying at home which has negative impact on physical condition of the elderly. It is known that fear of falling is often associated with the prior experience of fall (**Arfken, 1994)**.

Fear of Falling (FOF) is a health problem of elderly population and can be observed even in elders who never fell. FOF may cause decrease of functional activities and is strongly connected with adverse outcomes such as functional decline, falls and depression. Activity limitation due to fear of falling may cause loss of independence and reduce the social interaction, which in turn lead to physical inactivity and lower quality of life (**Dias, 2011)**.

Older adults whose activities are limited by FOF are in higher risk of fall because activity restriction may lead to functional decline and increased risk of falls in the future. Dias et al. emphasise that variables such as depression, exhaustion and social activity are strongly connected with activity limitation due to depression and fear of falling.

Fear of falling is associated with lower quality of life and limited mobility what bears out the need for effective interventions to prevent and limit the consequences of falls among older adults (**Arfken, 1994).**

There is still lack of full understanding of the factors that allows to predict falls in high risk populations (**Morrison, 2013**).

To assess the probability of falling we should focus more on intrinsic factors (both physical and cognitive) rather than extrinsic measures (such as weather or ground conditions). Morrison in his study mention several scientific evaluation tests: Berg Balance Scale, the six minute walking test, the performance oriented mobility assessment, timed up and go, the functional reach test, physiological profile assessment, to evaluate probability of falling.

Those at risk can be identify by screening, which as an assessment tool needs time to provide comprehensive and accurate results about risk of falling. There is no easy and fast tool that will work for all elderly at risk (**Morrison, 2013)**.

Continuous activity monitoring is necessary to detect the best timing for implementation of intervention in order to prevent the activity decrease which may cause negative events such as falls.

There are many different tools to monitor senior's activity. Within REACH project different activity-tracking bands were tested as the most simple and easy applicable.
In early testing with the testbed partners ZuidZorg in Eindhoven the Netherlands, researchers from the TU/e found that technology acceptance among this population of seniors varied. This early observational test attempted to create a baseline understanding of the level of physical activity and the kinds of activity members of the ZuidZorg community centre did on a daily basis. For this early test, senior participants were asked to wear a wearable activity tracker. Participants volunteered after hearing presentations from the TU/e research team explaining the aim of the study. During the recruitment phase before the start of the observational study several potential participants expressed concern about knowing how to work with, charge and extract data from such a wearable. In order to make potential participants feel the most comfortable and to make participation as appealing as possible for a wide variety of seniors, researchers at the TU/e decided to utilize the Xiao Mi Band as the wearable tracker in this trial. The benefit of the Mi Band over the fitbit, for this trial was that the Mi Band only needs to be charged about once a month while the Fitbits battery only lasts up to one day. Furthermore, the Fitbit allows participants to continually be influenced by the data it displays on the little screen. Though, for participants the wearing of any device and the knowledge that their activity is being tracked is in itself an intervention which may cause them to deviate from their regular physical activity, researcher at the TU/e reasoned that the continuous feedback on the Fitbit might have an even greater influence on the activity patterns of the seniors. One participant discontinued their participation in the study explaining that just knowing that the band was measuring their activity and being reminded of this fact constantly due it having to be worn continuously, gave this participant a lot of stress. This participant expressed feeling guilty about not being physically active enough. More participants in the test seemed not to mind wearing the Mi band activity tracker and two seniors agreed that they received attention due to the wearable and were proud to report they were taking part in research for the TU/e and the EU. As the primary aim of this initial study was to observe a kind of baseline of the level of physical activity seniors already engage in and to learn which kinds of activities might naturally be associated with a higher level of physical activity, it was undesirable to have seniors alter their regular patterns of physical activity during these three months.

Observations in this early trial seem to indicate that an increase in confidence and or self-efficacy can promote technology acceptance and that practice and collaboration in workshops can help facilitate this increase in confidence and or self-efficacy. In order to collect the data from the Mi Bands researchers from the TU/e held workshops at the ZuidZorg community centres every two weeks over the course of the three-month period. In half of these workshops the data was collected from the Mi Bands by student research assistants and provided to the seniors on paper in the form of lists: dates and number of steps. In the other half of the workshops seniors were guided through the process of collecting their own step data from the Mi Band accompanying application, the Mi Fit application. Researchers from the TU/e overserved from the beginning to the end of the trial period a change in the attitude and the confidence with which seniors approached the data collection of the wearable sensor. Initially several participants had expressed concern about the using the MIFit application on a smart phone. However, at the end of the trial period many if not all the participants seemed confident about extracting their own data from the provided smart phone with little to no guidance.

Participants did indicate some problems with wearing the activity tracker during this trial. Firstly, researchers noticed that the daily step data did not match participants qualitative descriptions of their day. This seemed to be because when wearing the tracker on the wrist it does not track activity very accurately during cycling nor walking with a walker. This was discouraging to seniors who did make the effort to be physically active and then did not see the result in their data. Thus, researchers provided participants who generally walked with a walker with necklaces with the same sensor. This solution also did not yield very accurate results however.

Other participants indicated they found the activity tracker uncomfortable to wear at certain times. Specifically, several participants mentioned they found the band uncomfortable while sleeping. One participant mentioned discomfort due to a wrist injury, while some other participants mentioned that the wrist band became uncomfortable when they experienced swelling of the wrists due to the weather getting warmer. With increased attention to materials and improvement to the sensors, these issues might be resolved.
Based on the knowledge from TU/e study to find the solution for constant monitoring of the elderlies is one of the challenges for REACH.

2.2 Baseline motivation of seniors and the "why" behind monitoring their behaviors

The success in motivating seniors depends on various factors, one of them being the moment of implementation of the motivational strategy (eg. When activity level has just started to decrease, when bad nutrition habits affects the senior wellbeing, when senior stops meeting friends/going out). There are various reasons why continuous activity monitoring is necessary. One of them is to detect the best timing for implementation of interventions (the best moment to motivate seniors e.g. to move). Depending on personality and health literacy, it might be wise to let seniors know about the actual relation of their behaviors as triggers for interventions. Making it obvious to the senior when it happens and why, giving some reasoning and education can be motivating for many.

2.2.1 Baseline motivation of seniors in both the pre & post – intervention scenario matters

Independent seniors living at home- under the risk of fall/frailty in the pre-intervention scenario differ in their experience of whether or not they have had a specific acute event. The prevention of inactivity and enabling seniors to live at home as long as possible does not provide immediate rewards to them. Instead, it is a long-term goal of not losing an ability, which at the starting moment of the intervention might be still a given. Coming up with preventative interventions that fit the most relevant risks for the individual is key then – providing the understanding that participating in a monitoring activity can help in tailoring such a program. Hence the first step of motivating seniors needed is a behavior change towards becoming compliant in wearing trackers (e.g. for activity level) and providing self-report (e.g. to capture food intake) regularly. Only the second step is behavior change regarding nutrition, socializing, lifestyle changes, activity, medication – depending on the outcomes of the monitoring, and then supported further by ongoing monitoring.
Therefore, the rationale behind monitoring in the pre – intervention scenario is twofold: Understanding the baseline status of behaviors & health status and then monitoring progress of (and compliance to) the intervention, enabling tailored dimensions of behavior change.

In the post-intervention scenario, the focus lies mostly on the way from hospital back home and prevention of patient’s hospital readmission. These seniors differ in their experience of how fit they are after their specific acute event and the intervention at the hospital. On top of their suddenly increased frailty, they now must also be open to change behaviors which they get “prescribed” by healthcare professionals based on symptomatic detection of frailty, which was performed at medical institutions. So, the first step of motivating seniors needed is a behavior change towards becoming compliant in wearing trackers (e.g. for activity level) and providing self-report (e.g. to capture food intake) regularly not to provide a baseline for intervention recommendations, but immediately to enable monitoring of progress over time. This compliance behavior change towards wearing trackers and self – reporting behaviors comes together, hence is intertwined with behavior change regarding nutrition, socializing, lifestyle changes, activity, medication.
Therefore, the rationale behind monitoring in the post-intervention scenario is to follow progress of (and compliance to) the intervention, enabling tailored dimensions of behavior change.

For seniors in both phases, their past/current lifestyle plays a major role. How large is the gap between what they are currently doing, and what they are asked to do in the future? Which context factors are helping them in changing their behaviors and which context factors can become potential barriers? When introducing solutions of the touchpoints, such aspects need to be taken into account, to facilitate successful interventions.

2.2.2 Tools to monitor senior’s activity

There are many different tools to monitor the activity of seniors. Within REACH project we have tested the wearables of Fitbit and MeBand, as they were seen as the simplest and easily applicable ones. User acceptance of and compliance to wearing a band are factors that provided some learnings over time. It proved difficult to engage seniors to wear a tracking band. Reasons why they were not willing to wear it constantly are for example that they found it uncomfortable, other reasons were related to ability rather than willingness, such as inaccurate measurement of steps. Other obstacles observed were charging problems. Solutions and mitigations put into place thus far are to organize every-week meetings to discuss undertaken activity and charging at the same time. Recommendations for the role of supervising (coaching) through the process of monitoring are for example to make older adults more confident about the change and its positive impact on their health and wellbeing.

2.2.3 Social aspects for motivation & the role of Gamification

As described in report **D14**, many Behavior Change theories mention social aspects as major factors for motivation. For example, “relatedness” (i.e. having close and affectionate relationships with others) as one of the three core psychological needs that drives behavior as part of the self-determination theory developed by **Deci and Ryan (1985)**. Others are the social cognitive theory by **Bandura (1977)** or “social proof” (people are more inclined to comply to a request, when they know that others have done so as well) as one of the six principles of persuasive design by **Cialdini (1984)**.

But what does it practically mean, how can the “social” factor be implemented in strategies for behavior change? Looking at the motivational strategy of providing triggers (**D14 chapter 3.3 “Triggers - Make use of different triggers at the appropriate times”**), an example is to show met targets to a senior (weekly stats) and how many people are participating in reaching the same targets.

Furthermore, using connectedness as a motivational strategy can come handy in relation to social factors (**D14 chapter 3.11 “Connectedness - Make use of social influence and support”**). It can have very motivating effects on seniors to provide them with opportunities to feel socially accepted by others or to enable social support for decision making during an intervention and for coping with the struggles of becoming and staying adherent to interventions related to nutrition, lifestyle changes, activity, medication.

Last, but not least, a helpful approach as part of gamification (**D14 chapter 3.9 “Gamification - Apply gamification to enhance user engagement”**) can be using socializers that fulfill the wish to get to know other people; the “tribe” need, that also comes to play in collaborative or competitive settings. But gamification does not consist only on providing (social) rewards. As described in **reports D2 & D14**, gamification has been shown to be a combination of persuasion, education and incentivisation, with socialisers being only one of many possible rewards. Gamification becomes more efficient when taking the internal motivations of users, and player types into account (**Bartle, 1996**) which relate to these needs: achievers (want to collect points and complete levels; the self-need), explorers (want to explore and find secrets; the hunt need), socializers (want to get to know other people; the tribe need), killers (want to win and increase their self-esteem; the self-need). What kind of games are the most engaging also depends on the player type the individual senior belongs to – which can be challenging to determine.

2.2.4 Application in touch points 1 & 2

As described already earlier in report **D14**, “Touchpoints” act as “tangible” front end towards the end users (seniors). Touchpoints will mainly materialize as “furniture” in a broader sense, i.e. elements that can be placed and moved within a certain environment or setting (e.g. beds, bath furniture, mobile walkers/standers, large scale interfaces, smart flooring tiles, smart tables, etc.) but also as ambient sensor add-on modules and wearables. 5 physical touchpoints will function each as data gathering and intervention devices, which are bound together by cross-sectional, integrated engine (i.e. platform) functionality. As examples, touch point 1 is a Personal Mobility Device, touchpoint 2 is an Active Environment (see **Figure 1-1**).

2.2.5 Touchpoint 1

The theme for touchpoint 1 is "frailty and risk of falls". Early detection will be done only with the sensors; when then risks of falls or signs of frailty are detected the mobility device comes in as a safe activation and training device. The mobility device optimally follows (and can modularly be adapted to) the person throughout the patient journey through different care stages.

The programmed interventions of touchpoint 1 are that the mobility device functions as a kind of medical home or indoor fitness device. A screen and motion sensor allows for an interactive scenario where the users can play games or follow mobility training instructions. Like in a fitness device in a fitness studio, our device should contain some basic (and modularly separable) physiological sensors on board that allow to monitor the training progress and outcomes.

Goal must be to motivate the elderly (e.g. through gamification) to use the equipment to train a) themselves, b) or in a community (e.g. a center of ZZ), or c) together with care personnel in an institution to achieve a better level of mobility. At best, this results in an improved mobility, e.g. in terms of distances walked (also without using the equipment).
Motivational strategies applied for touchpoint 1 are: gamification, social influence and social support, goal-directed behavior, self-reflection and personalization and customization.

2.2.6 Touchpoint 2

The theme for touchpoint 2 is "mobility". The idea here is to detect and prevent decrease of (micro) mobility in a care environment early on. Therefore, performance levels (positioning problems, balance/falls) are measured and monitored. Mood should be tracked in the future as well, both based on the physiological measurement + track mood by clinical professionals e.g. via depression questionnaire (and correlate/match both).

The programmed interventions of touchpoint 2 are a combination and integration of "furniture" components (bed + bed periphery + mobility device (activeLife) + toileting support) to a seamless in-house "transfer and mobility chain" that should facilitate a significant increase of mobility in the patient room. Both the personal mobility device (TP1) and the Playware tiles based "gaming and training" system (TP4) may later on be used as additional interventions.

Motivational strategies applied for touchpoint 2 were implemented in various forms in the workshop approach taken in the beginning of the activity. As mentioned, practice and collaboration in workshops were causing an increase in confidence and or self-efficacy and can promote technology acceptance and can help facilitate this increase in confidence and or self-efficacy. In the future, the idea to meet challenges three and four as described in 2.1 are e.g. that the coaches will apply triggers in the communication with seniors (as mentioned in D14, see Thaler, Sunstein, 2008; Kalbach, 2016; Eyal, 2014), and that the ZuidZorg activity center itself can be used as a social factor for motivation (as mentioned in **D14**, see **Cialdini, 1984; Fogg, 2009; Resnick et al., 2002; Prochaska & DiClemente, 1992**). These should lead to engaging seniors in activity in patient and therapy rooms and motivate to participate in and adhere to therapies and scheduled trainings/interventions.

3. Intervention product service system concept

The REACH system represents a solution which tries to prevent elderly citizens from losing functionality and declining abilities in performing Activities of Daily Living (ADL) through implementation of Product Service Systems. In this section, more details of the Product Service Systems (PSS systems) will be discussed, according to two previous REACH deliverables:

- according to REACH deliverable **D3** for task **T1.3**, the initial creation of PSS systems which was addressed throughout a series of workshops at different partner sites
- according to REACH deliverable **D4** for task **T1.4**, the overall system architecture and the concept planning and implementation

The Product Service Systems will be the front line interfaces of implementing the goals of the REACH project for example monitoring the elderly, early detection of future health trends (through methodologies form data mining, big data and smart data analysis), in time intervention and post intervention monitoring. Furthermore, based on these PSS systems REACH Engine and REACH Touchpoints were created.

In order to address the aforementioned specifications, the REACH was defined as a project to implement and develop a sensing-monitoring intervention system which is utilized in an unobtrusive manner in various care settings and living environments of the elderly. The system will have the following capabilities:

- Using a set of sensors to detect and monitor previously selected health data, behavioral patterns and health status.
- Predicting future health states, risks or events (for example loss of function, frailty, heart attack or stroke).
- Providing a set of customized services and products to fulfill stimulating and supporting physical and mental activities among the elderly.

Early intervention realized by REACH should increase the time spent in the desirable physical and mental health status and reduce the time period spent in health care facilities and hospitals.

3.1 Schematic design of early detection strategies both pre- and post-intervention.

Several purposes should be fulfilled by implementing these Product Service Systems. At first, signs of frailty, loss of function or other health risks should be detected using the considered sensors and then an intervention should be proposed so that any further risks can be prevented. Secondly, after an intervention the monitoring continues to assure future safety and prevention. As a result, two very important concepts should be addressed in this section. Firstly, the early detection strategies to detect frailty and signs of weakening or other health risks in pre- and post-intervention states. Secondly, motivation strategies, from technical point of view, to stimulate the elderly to have more physical and mental activity.

In the first step, early detection should be implemented using several sensor systems. To mention a few examples of the considered sensors in the Touchpoint 1 (the Mobility Device) one can point out ECG/EMG sensors, SmartCardia sensor and Microsoft Kinect.

Using the ECG and SmartCardia sensor the heart rate and other vital signs can be monitored. Using these values and considering the patients' health parameters (e.g. weight, age, smoker or non-smoker, etc.) and using the data mining (big data and smart data) methodologies (provided a rich data set for pre-processing is existing at the time) the REACH system with high accuracy can early detect many future health risks and conditions.

Additionally, using an EMG sensor in Touchpoint 1 provides the capability to monitor the lower body muscle activities of the user. This data will provide the REACH system with frailty measurements (loss of muscular functionality in lower body part) and with enough information to perform preemptive intervention to avoid the future injuries or to monitor the physical improvements of a previously ill user. Using this approach and a properly implemented motivational strategy the REACH system can realize a timely intervention system to motivate elderly citizens to participate in more physical activities. Furthermore, the implemented EMG sensor can be used for motivating the users who are not one hundred percent paraplegic (but they suffer from injuries and diseases of nervous system) by showing the muscle activities when they try to move the lower body part.

By providing the end-user with actual health improvements on for example better blood circulation, muscle strength improvements, improved heart rate and etc. the end user can be further motivated to use the REACH system and monitor their health status.

Technologies which are successful in motivating long-term healthy decision-making can prevent or delay illnesses or the path to medically expensive treatments. For instance, obesity has been considered as an independent risk factor for coronary heart disease, hypertension (high blood pressure), Type 2 diabetes, stroke, gallbladder disease, osteoarthritis, sleep apnea, and several types of cancers. Consequently, using technology to prevent medical conditions such as obesity, heart attacks or brain strokes will lead to alleviating financial pressure on the medical insurance systems.

In the ubiquitous computing field, information processing is thoroughly integrated in everyday objects and activities. According to a research by **S.S. Intille in year 2004**, there were two major emerging trends regarding the context aware algorithms for preventive healthcare applications:

1. Rapid adoption of powerful mobile computing devices
2. The emergence of real-time context-aware computing

The two mentioned trends enabled a new class of persuasive interfaces to create behavior change strategies by providing timely information to users at points of decision. Based on a research by **S.S. Intille**, there are four essential components for any motivational behavior change strategy to provide a minimum level of effectiveness:

1. presenting a simple, tailored message which is easy to understand
2. choosing an appropriate time
3. choosing an appropriate place
4. using nonirritating, engaging and tailored strategy (even after many presentations)

Furthermore, the aforementioned criteria in combination with the four identified categories of motivational strategies for REACH Touchpoints (see **REACH deliverable D4**), including Gamification, Social incentives, Goal-directed behavior and Self-reflection/Self-efficacy will lead to efficient utilization of sensor systems for the purpose of motivation.

3.2 Schematic design of modular add-ons for the PI2Us for the person-individual, customized fully body mobilization/training of users for user-specific, target oriented intervention purposes

This section will first provide a detail overview and then an exemplary integration with main focus on the two previously designed PI^{2}U-Bed and PI^{2}U-Stander. The prototype design and naming of each PI^{2}U device was initially introduced in REACH **deliverable report D21**, in case of need for further details please refer to this document.

3.2.1 PI^{2}U – Bed

One of the most serious problems when taking care of immobile, frail and elderly patients is the prevention and management of pressure ulcers, also known as bedsores and decubitus. They are localized visible damages to the human skin and/or the underlying tissue near a bony protrusion, which are caused by persistent external pressure. When the contact pressure over affected skin areas leads to exceeding the blood pressure in the capillaries over a long period of time a decubitus develops. Usually, a period of two hours is considered critical. Once emerged, pressure ulcers are very painful for the affected patients and the treatment is considered to be highly complex, expensive and the healing process takes a long time.

Considering the anti-decubitus treatment, it is of great interest to know exactly how high are the shear forces acting on the patient body. In the care environment, usually the immobile patient has to be turned or moved nearly every two hours, e.g. by a nurse. It will be very useful to know whether the turning activity can be postponed for a few minutes or an hour leading to more convenience for the patients, as well as the care givers, to have longer sleep periods especially at nights.

Therefore, as greatly detailed in other REACH deliverables, solutions such as the BodiTrak monitor is able to help such cases. The BodiTrak Monitor is composed of a stretchy Lycra sensitive material on which the patient is lying and a software based on the **Reswik Rogers** time/pressure curve to help the caregiver to monitor and manage the pressure against the skin surface of a patient. BodiTrak shows how high the pressure and the shear forces are, and how long they are in a certain part of the body. The real-time feedback helps nurses and care givers to find a position with better pressure distribution. The software also includes a time-to-turn alarm with selectable time slots. Caregivers access the BodiTrak Monitor information with a tablet wirelessly connected to the system, or they can view the data on the computer in a web browser in the nursing station. Presented at the tablet or mobile device, the gradient, which is an expression of how the pressure changes from one place to another over patient's skin, is displayed in mmHg/cm. Warmer colors indicate rapid changes in which shear forces can adversely affect the skin. Consequently, integrating monitoring systems such as BodiTrak will be critically helpful for the PI^{2}U-Bed platform to prevent and manage elderly citizens prone to or affected by pressure ulcers.

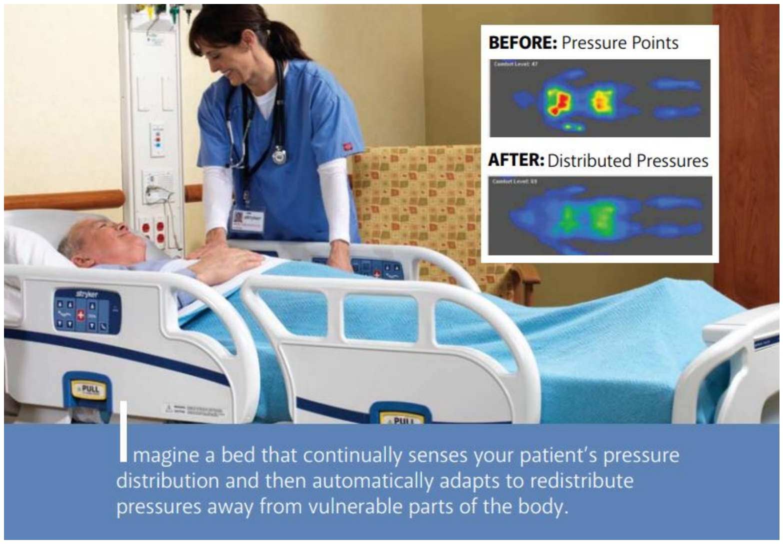


Figure 3-4: BodiTrak monitor help mitigate user's skin pressure (http://www.boditrak.com/)

The design of the PI²Us embraces the platform strategy. The design of a variety of products using the same modules of components is called the "platform". A platform is useful for mass production, allowing savings and easy manufacturing. The platform strategy provides a structured modularity in more levels and a high degree of standardization (**Jose & Tollenaere, 2005**).

The design of the PI²Us also follows modularity principles. The type of modularity to be applied in the PI²Us' design is mainly Bus Modularity. Bus Modularity refers to providing a common structure, which allows modules of various type, number, and location to be plugged in. The appearance of this system can variate through the type, number and location of the added modules (**Mascitelli, 2007**).

Following these principles, the PI²U-Bed will be designed as a modularized smart bed integrated with various functions, such as movable table, breath detection, displaying interface, and pressure sensors. It integrates the modularity function which features the ability to connect additional functional modules such as bathing, privacy, and dining (see **Figure 3-6**). It also features a screen that allows visualization and in-bed training function (see **Figure 3-7**).

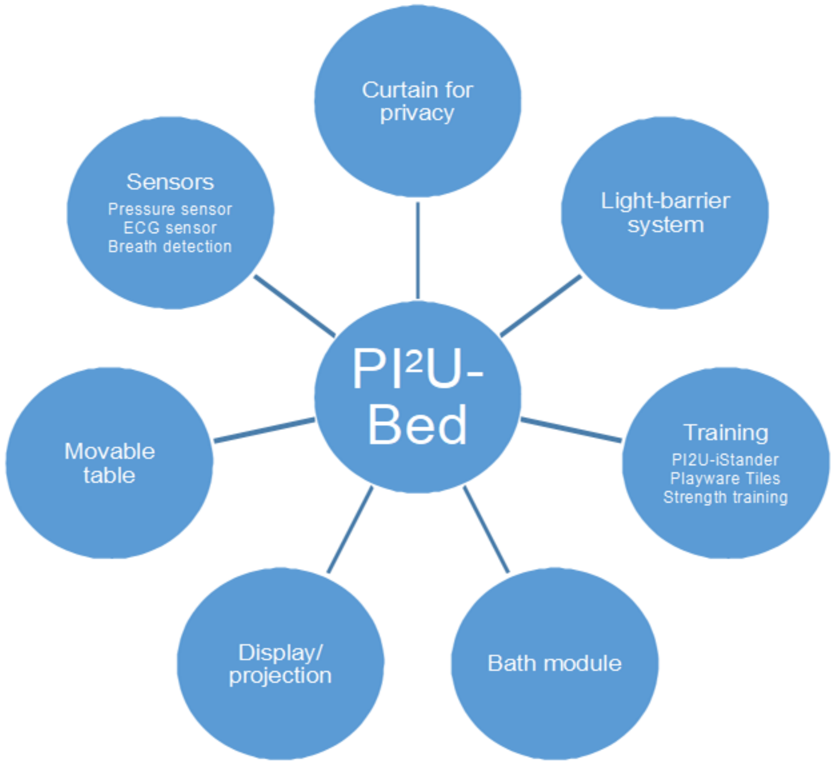


Figure 3-6: Functions to be integrated into PI²U-Bed platform

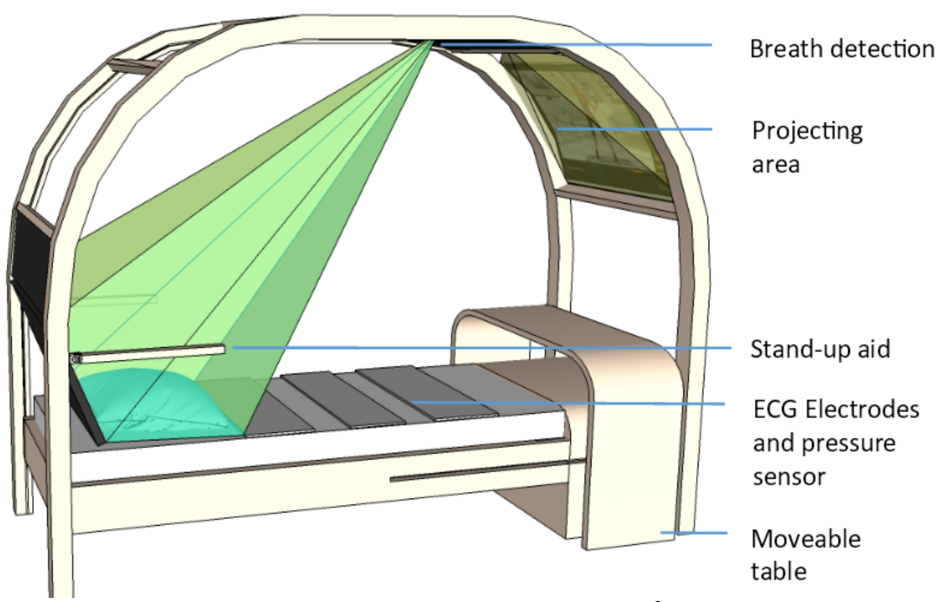


Figure 3-7: Initial visualisation tof the PI²U-Bed

3.2.2 PI²U – Stander

The design of PI²U-Stander based on Alreh Medical's Stander device, which is an advanced dynamic stander designed to support rehabilitation of musculoskeletal system in a step-by-step manner for people with deep physical disabilities (e.g. paraplegics caused by traumata, multiple sclerosis, tumors etc.). PI²U-Stander is mainly used in patients' living environments together with other PI²Us, in order to assist and promote activities of daily living (ADLs). In REACH project, it is considered to add multiple sensing systems to the PI²U-Stander, such as EMG sensors and pulse sensors. In addition, the model has mobility function, which can further help the elderly to move between different locations and gradually train their muscles for standing and walking (see **Figure 3-8 & 3-9**).

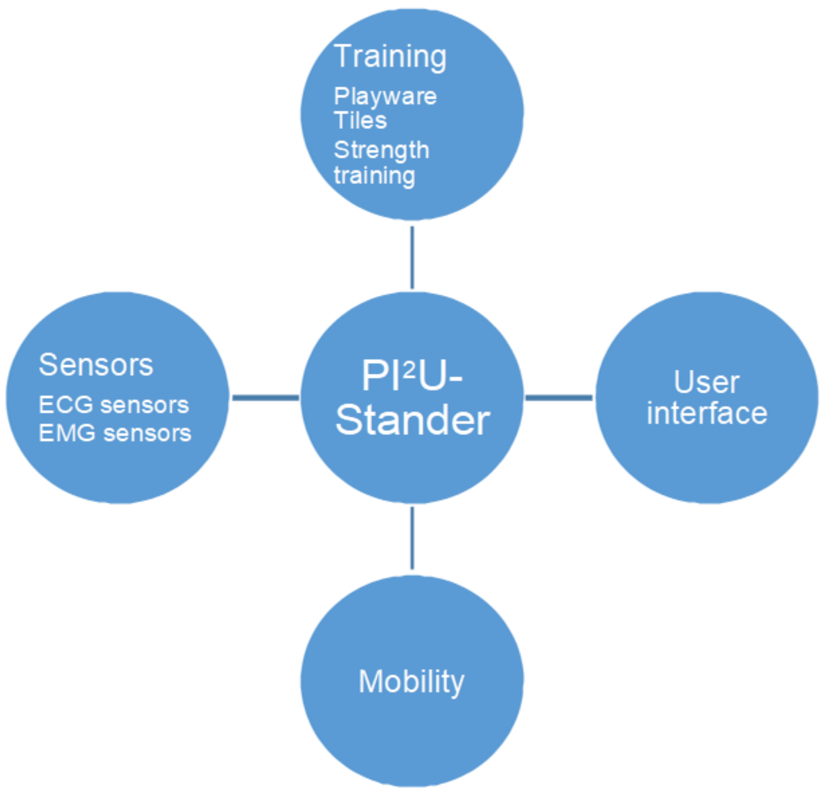


Figure 3-8: Functions to be integrated into PI²U-Stander platform

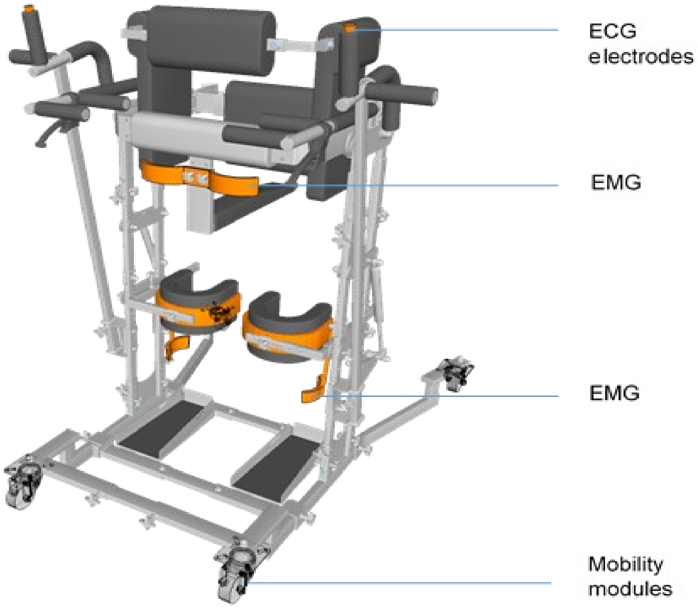


Figure 3-9: Initial visualisation of the PI²U-Stander

3.2.3 Integration scenario: care room

Besides the aforementioned sensing functions, the PI²U-Stander provides two main functions: training and mobility. Figure 6 demonstrates a care environment scenario where the PI²U-Bed as well as the PI²U-miniArc (for details see **REACH deliverable D21**) are installed in a care room. The patient will be able to do physical training with the help of the PI²U-Stander and the Playware Tiles, following the instruction displayed on the wall's projecting area from the PI²U-miniArc device.

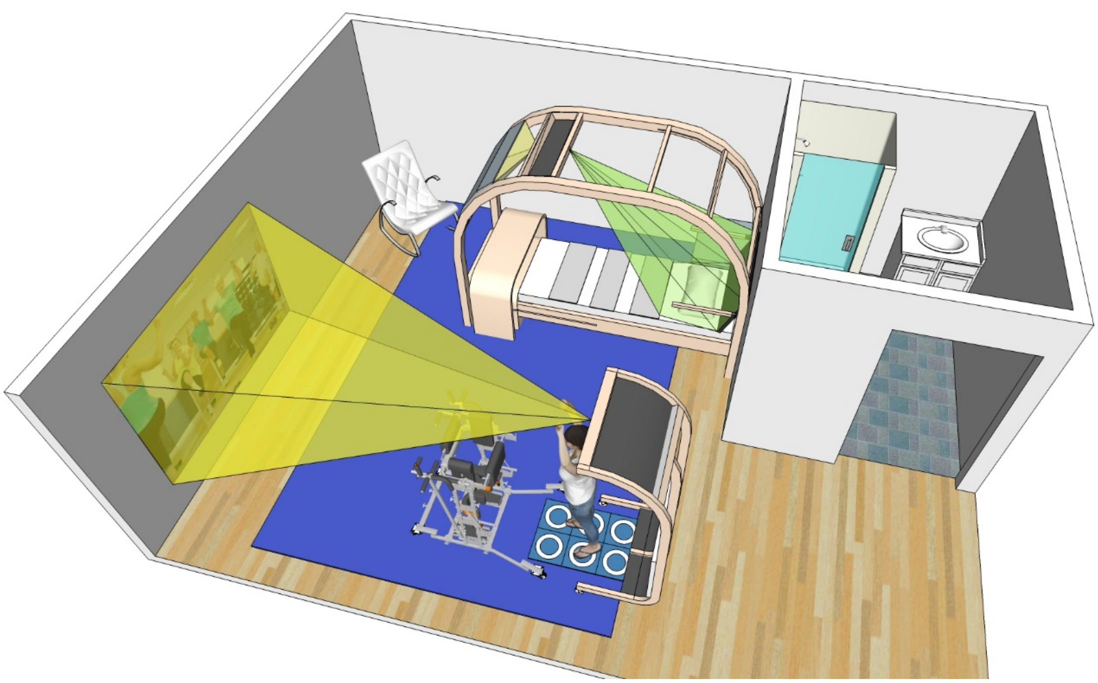


Figure 3-10: Simulation of PI²Us application in a care room scenario

Meanwhile, the PI^{2}U-Stander also serves as a mobility device for the patient's transfer between different locations (e.g. bed, bathroom, training area, door, etc.) and different PI^{2}U platforms (e.g. PI^{2}U-Bed, PI^{2}U-silverArc, and PI^{2}Us-miniArc). For example, when a patient resting on the PI^{2}U-Bed who wants to get up to go to the bathroom, PI^{2}U-Stander can help the patient move from a sitting position to a standing one, so that the patient can slowly move to the bathroom and the toilet with the assistance of the PI^{2}U-Stander (see **Figure 3-9**). Through those processes, patient can gradually strengthen their muscles and redevelop the ability for daily activities such as sitting, standing, walking and others.

During the night when the patient rests on the PI^{2}U-Bed, sensors such as breath detection, ECG, and pressure sensor on the mattress can ensure that the patient is going through a properly monitored sleep. Once an abnormal event occurs such as abnormal breathing and unbalanced body pressure distribution, the system can make sure that the caregiver will be informed to support the elderly in a timely manner. Thus, the application of the PI^{2}Us establishes an autonomous care environment in the care room.

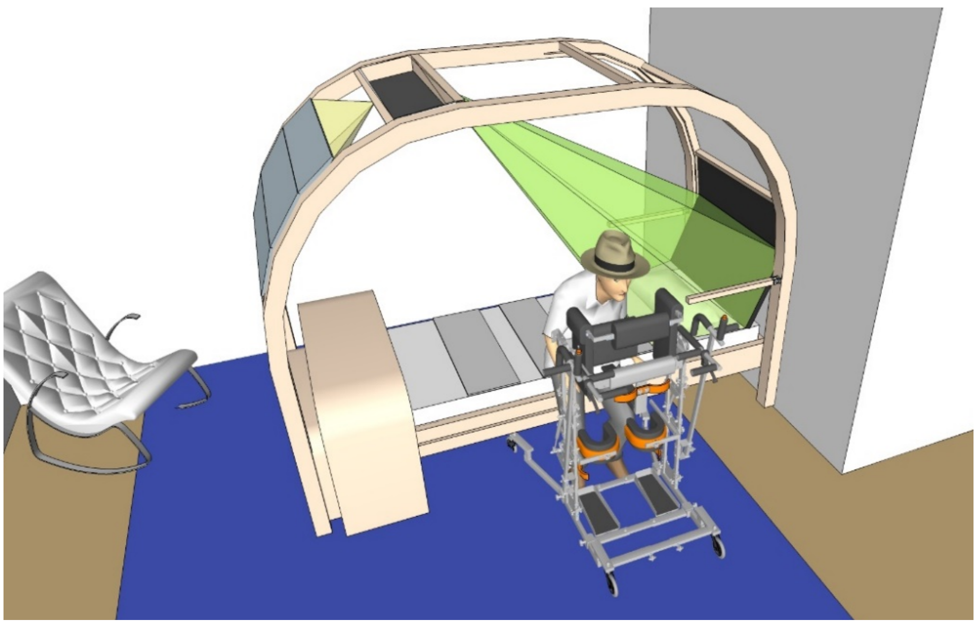


Figure 3-11: Simulation of PI^{2}Us application in which the PI^{2}U-Stander as a mobility device helps the patient stand up from the PI^{2}U-Bed and move

3.3 Schematic design of interfaces and connectors necessary to connect add-on devices

During the time which has passed from start of the REACH project, many sensor systems were studied or suggested. However, the development and realization of these systems depend on many limitations such as budget and time. To provide a more technically detailed overview of sensor systems which are under development or developed, the following section is provided. Additionally, it should be clear that the main development phase is still pending and of course other sensors will be realized. There are many sensors which are planned to be realized in REACH but not all mentioned in this section (more can be found in **REACH deliverable D5**).

3.3.1 Capacitive Electrode and Photodiode

The PPT is the time difference between a heart contraction, recognized by the R-Peak of electrocardiogram, and the arriving pulse wave which is detected by pulse sensor (can be seen in figure below). According to these three studies, the PTT value is directly related to systolic blood pressure meaning that with reduced interval of PTT the blood pressure increases. Therefore, if the linear relation between the blood pressure and PTT interval is known, the blood pressure can be easily estimated.

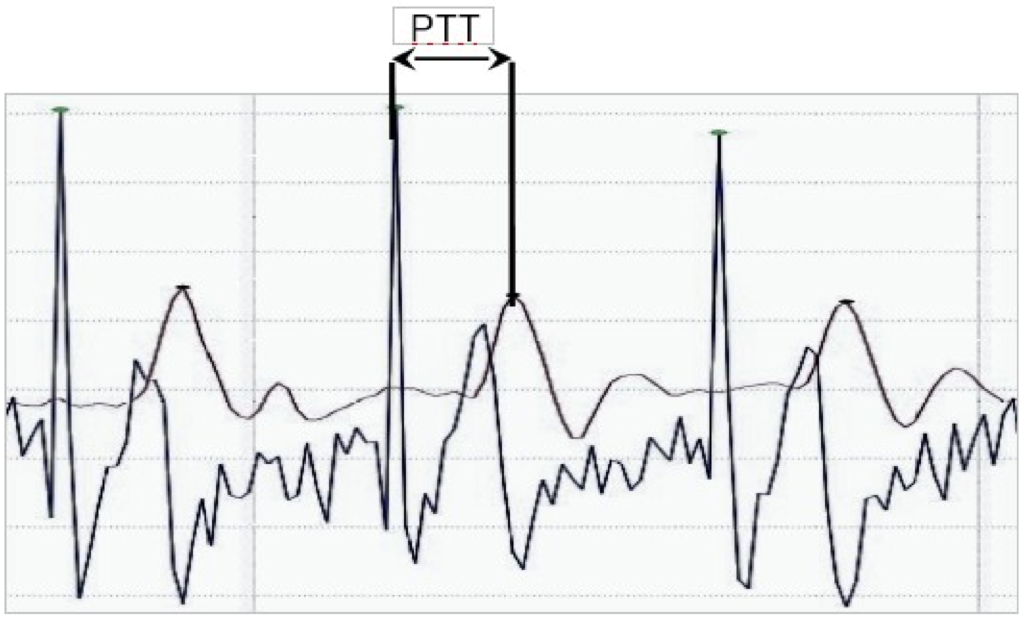


Figure 3-12: The PTT interval between the capacitive ECG and the pulse sensor curve

Considering the capacitive electrodes two different modules have been implemented, both of which concluding the same results (**Güttler, 2016**). In any case, it should be considered that the REACH project requires monitoring through utilization of dry Electrocardiography electrodes. It is worth mentioning that such a sensing system would also function using standard Electrocardiography electrodes, however using the electrode gel in context of REACH project will undermine the unobtrusive monitoring approach in addition to adverse chemical reaction of glue and electrode paste with the human skin (**Kemis, 2012**).

Implementing active electrodes can measure ECG signal and blood pressure through PTT, however the high sensitivity, which is necessary for this application, will lead to signal disturbance with many noises. In order to avoid this problem, proper shielding for the active electrodes must be anticipated.

In order to read and process the incoming ECG signal from the capacitive electrodes, the electrodes were connected to an analog circuit and then were connected to a single board computer. A schematic of electrical circuit can be seen in **Figure 3-13**.

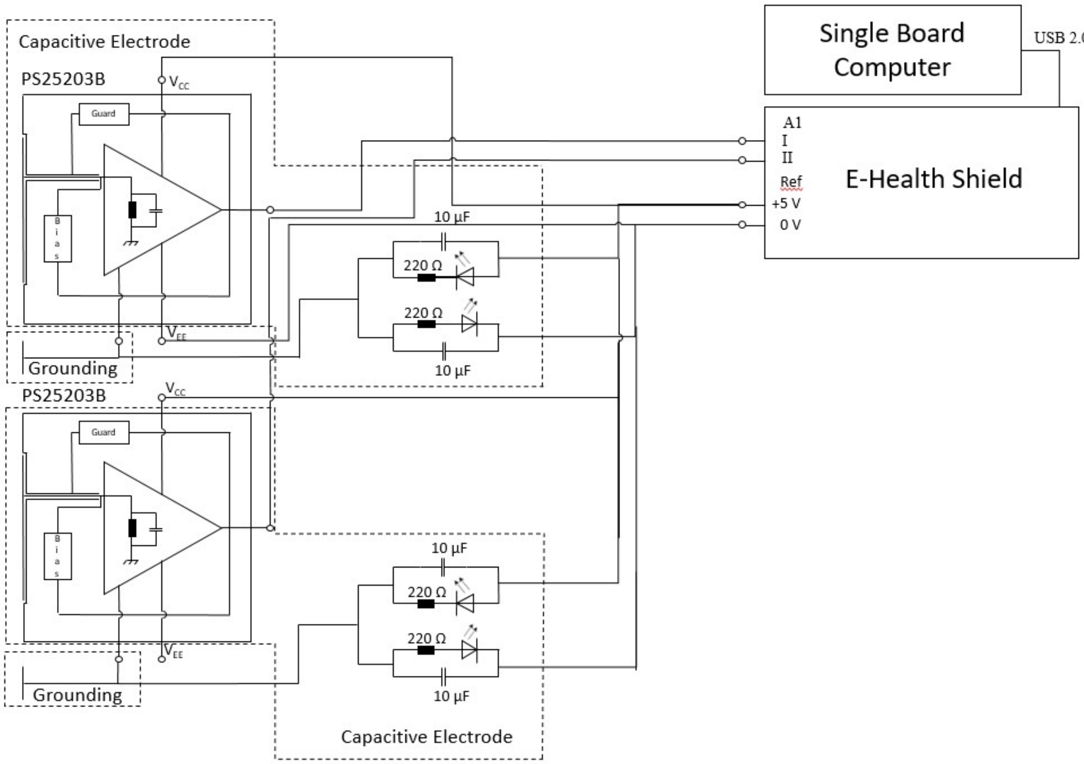


Figure 3-13: Circuit scheme for the cuff-less Electrocardiography signal monitoring and Blood pressure monitoring

The implemented hardware configuration allows to utilize the single board computer as the sensor interface. Implemented software on this single board computer will process raw data to fulfill three main objectives:

- Processing raw data
- Displaying results
- Storing and forwarding results

The following flow chart in figure 10 provides an overview of how the software could work to process the raw data.

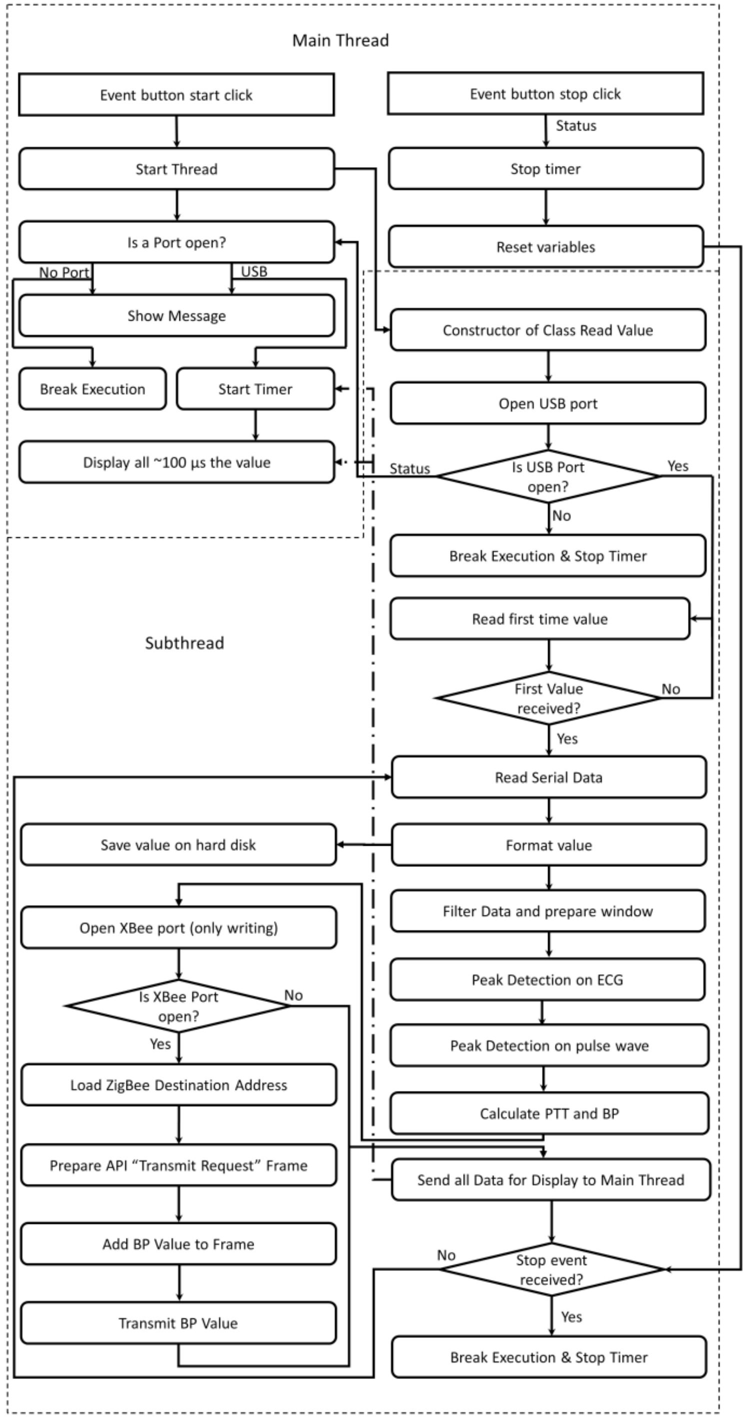


Figure 3-14: Flow diagram of the overall algorithm executed on the single board computer

3.3.2 Pressure Mattress

In order to address the previously mentioned concerns and issues regarding prevention and treatment of the pressure ulcers, there has been an extensive study on different pressure mapping sensor systems which can be purchased and properly altered and integrated to support functionalities and requirements of the REACH project. Many of these pressure mapping sensor systems has been shortly introduced in REACH **deliverable D21 section 4.3.2**.

Such a sensor is in fact a two dimensional pressure sensor grid which provides a body pressure map when a person is lying on the mattress. Of course this sensor should provide proper resolution and pressure measurement to be effective. The duration of stay in one position, which will not lead to the pressure ulcer development, highly depends on the intensity of the pressure which can be highly variable. The duration value and the alarm for the caretaker to move the immobile patient will be calculated using a software system deployed on a single board computer. **Figure 3-15** shows the result of a two dimensional pressure sensor from a sensor provider called Sensor Products INC.

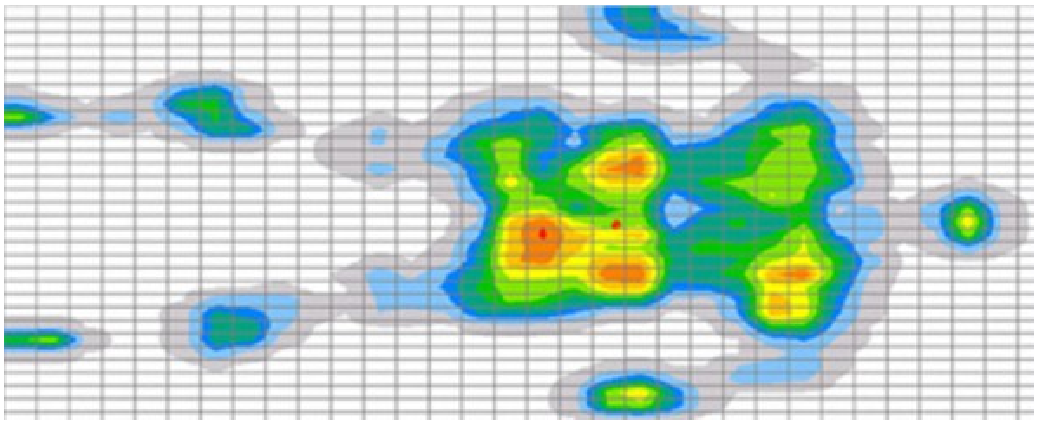


Figure 3-15: Body Pressure Mapping - Warmer colors showing higher pressure points

When such a sensor including the Application Programing Interface (API) is purchased, integrated and tested as a sensor in the PI^2U-Bed, then the provided raw data from this sensor can be processed using a single board computer. In addition to feeding this data to the REACH Engine and creating a rich data set for future data mining methodologies, this data would be locally processed and the result can be presented to the caretakers so that they have a better understanding and estimation on how and when to move the immobile patients. Such a sensor can have an impressive effect on the prevention and early detection aspects of the REACH project.

Due to the high estimated costs of such a sensor, the current status of this sensor is under administrative work. The plan is to purchase this sensor as soon as possible and start the development and integration.

3.3.3 Playware tiles

This sensor which is mainly introduced in **REACH deliverable D5** consist of an embedded system which communicates with a backend server to transfer, monitor and track mobility data. The Playware Tiles are aiming to fulfill the following tasks among the elderly:

- Improve the mobility prevent falling accidents
- Improve the balance by strengthening lower body muscles
- Improve quality of life by conveying exercises
- Create motivations using data tracking and showing improvements

This sensor which is developed by one of REACH partners (Center for Playware at DTU) will be integrated in PI^2U-silverArc and PI^2U-miniArc for Touchpoints “Personal Mobility”, “Active Environment” and “Gaming and Training”.

Since these sensors are ready products from a REACH partner, the status quo regarding integration and further development of these sensor is that after a very time consuming communication between the partners, recently an NDA agreement was signed and confirmed so that TUM can access the confidential data and start further developing of these products.

The plan is to feed the raw data from these sensors into REACH Engine for data analysis and mobility calculation. Furthermore, if possible adding more sensors to these tiles for capturing other signals and variables.

4. Schematic design of PI²Us – compatibile multifunctional rehabilitation (mobility – focused) system (activLife)

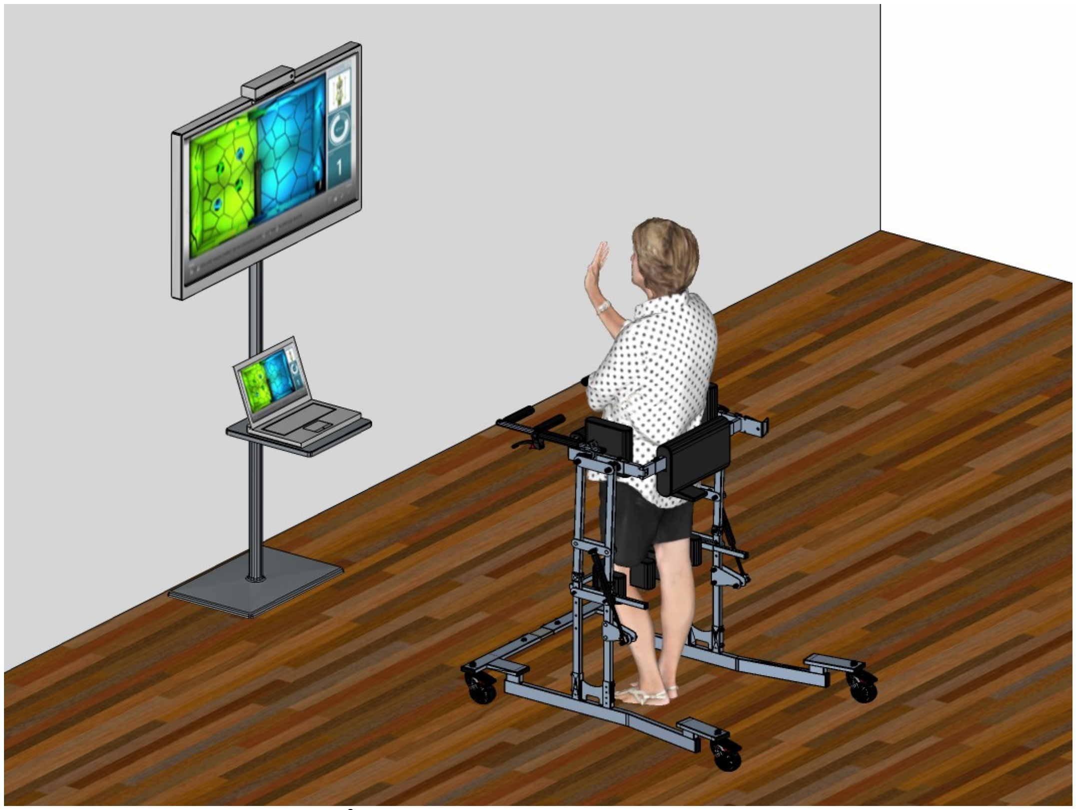


Figure 3-16: PI²U – compatibile rehabilitation system (activLife)

Regular physical activity plays a big role in every stage of life. Systematic physical activity should be included in the lives of elderly people. Unfortunately, their daily activities are not sufficient to meet the WHO recommendations on the required minimum and to meet the proper fitness levels (**Halat, 2004).** Sedentary lifestyle, common in the elderly, adversely affect a number of body functions, which are necessary to maintain the autonomy and independence in the daily functioning (**Merc & Co., 2006**). In addition to its positive effect on mortality, regular physical activity is one of the most important factors for the so-called positive ageing (**National Center for Chronic Disease Prevention and Health Promotion, 2004**). Physical activity plays an important role in better subjective perception of the quality of life among seniors. Numerous evidences show that regular physical activity is associated with better mobility, improved daily activities, as well as decreased anxiety and occurrence of depression in people over the age of 65 (**Evans, 1999; Leveille, 1999; Psaltopoulou, 2008**). The beneficial effect of exercises is particularly noticeable in elderlies already affected by disabilities. Of note, systematic physical activity also positively affects autonomy (**Psaltopoulou, 2008**). Importantly, the use of simple forms of movement in such a way that physical activity is associated with pleasure, relaxation and fun is the most effective among seniors (**Evans, 1999)**. That is why specialized intervention programs are needed to properly impact the key parameters such as muscle strength or dynamic balance, as well as cognitive factors (**Leś, 2017)**.

The ActivLife rehabilitation device is designed to activate the motor and mental activity of people of age whose daily activity levels have decreased. ActivLife is applied in the prevention of falls of the elderly, and due to the simultaneous combination of motor and mental exercises, it provides effective support for cognitive processes. The multifunctional rehabilitation system is addressed to almost all seniors (in good, medium and poor health condition) and can be used in both home and hospital use-case early detection scenarios designed for Reach project.

Home – for senior living at home independently or with limited support as well as for elderlies who are living at home with permanent care provided (but without severe cognitive impairments)

Activity centers – user operated or facilitated by sport/training coach. The device will be equipped with dedicated functions/modules supported only by the coach

Care homes – user operated or facilitated by personnel. The device will be equipped with very simple interface and will serve as a safe and cost efficient activity device

Medical institutions – user operated or facilitated by physiotherapist, with limited scope of teaching patients for home/activity center/care home use later. In this role it is training device, not an ordinary hospital rehabilitation device.

ActivLife will be designed with several functionalities:

- Physical activation
- Rehabilitation
- Mobility
- Bed assistive functions (transfer, mobility, potentially also toileting)
- Activation of cognitive function (neurological rehabilitation as well as dementia prevention)

The designed mobility device will consist from modular components which will be adjusted according to physical and mental health condition of the user. For those with less mobility and strength some elements of the device will be optional (i.e. stable base of support) and some elements will be adjusted to the user (i.e.corset size, supporting springs system).

Physical activation module is being built on safe standing as a fundamental life function (**Figure 3-16**). The main goal is senior activation with the stress on increasing the strength and the sense of balance including unique fall prevention training. This solution will be applicable for users in good/medium health condition exposed to frailty.

Figure 3-17: Personal mobitily device – activLife by Alreh Medical

The device is equipped with a mechanism assisting in standing up called GymUp, allowing for mobility exercises of the ankle, knee and hip joints. It increases muscle strength of the lower limbs while performing squats and back stances. A special corset and seat ensure safety during exercises strengthening the back and abdomen muscles based on lifting the legs. ActivLife also allows to maintain a safe, upright standing position, and to perform balancing exercises as well as exercises activating the upper parts of the body using the multimedia program (**Figure 3-17**).

Interactive activation (games, videos, social communication) has 3 specialized functions:

- engages user (motivation)
- gives mental activation
- enforces physical activation

There were two gaming systems tested: Neuroforma and VAST.Rehab.

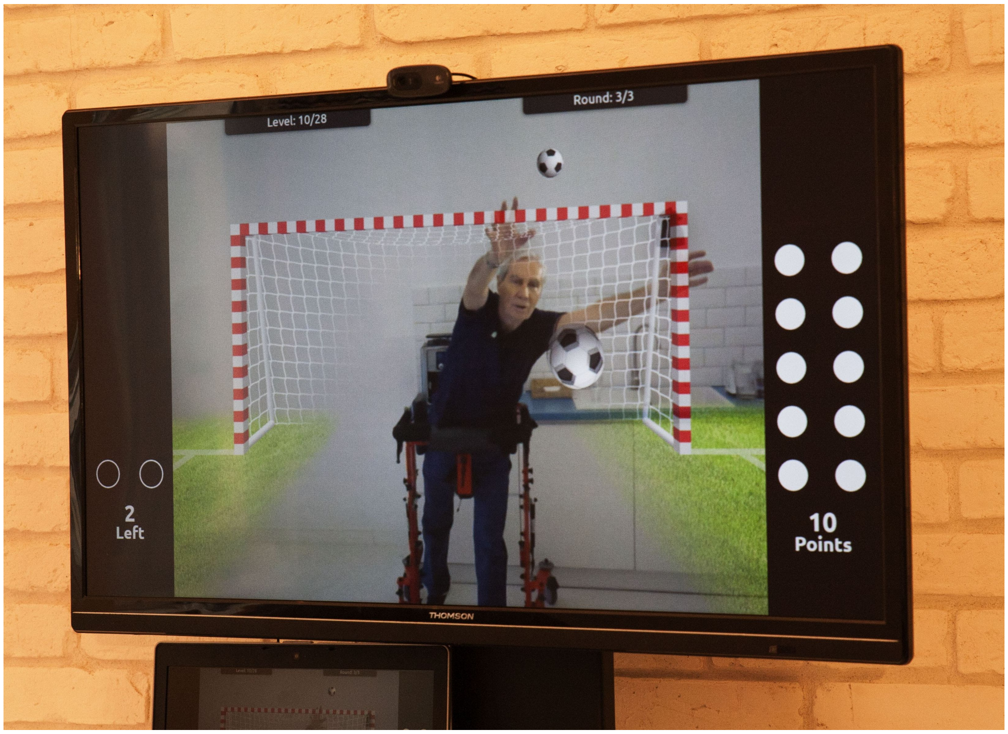


Figure 3-18: Neutoforma gaming system

Neuroforma is a computer program for motor and cognitive rehabilitation created by neurorehabilitation and neuropsychology professionals. Neuroforma is designed for patients with neurological deficits. It's particularly suited for the rehabilitation of patients recovering from a brain stroke.

The software gives the access to over 20 exercise modules. They engage both motor and cognitive skills. By Neuroforma exercises the user can improve e.g. movement precision, eye-hand coordination, joint mobility, muscle strength and endurance, perception and decision making processes, attention and memory (**Figure 3-18**).

The program gives the possibility to create own practice session with all the available modules. A practice session is a group of exercise modules of choice, which will start automatically one by one in the order that is set.

Neuroforma gives also the feedback. The program shows user results. After the practice session it is possible to see a report about the consistency and progress.

The results from early testing at HUG (**see section 4.1.1 of this deliverable**) showed that the Neuroforma software associated to the device were reported to have a clear interface and to be easy to use. However, from the caregivers' perspective, the design needs a bit of refreshing. In addition, the patients showed low interest in video games. Following the suggestions Alreh Medical decided to search for another option of activating gaming software already existing on the market and started to collaborate with Vast.Rehab.

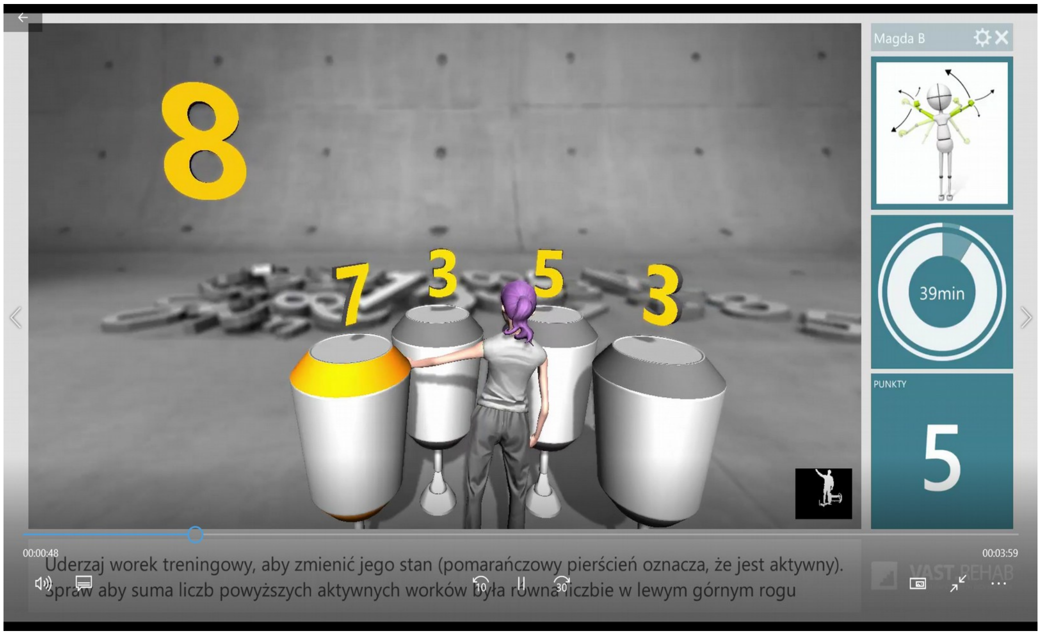


Figure 3-19: VAST.Rehab gaming system

VAST.Rehab is a fully-featured virtual reality rehabilitation system with the flexibility to work for everyone from small physiotherapy practices, to the largest hospitals and home environment (**Figure 3-19**). VAST.Rehab is easy to learn and use and helpful for therapists and sport coaches looking for convenient way to make their patients more motivated to participate in their rehabilitation process.

VAST.Rehab automatically tracks patient's progress. Once the user learns how to use the system while working one to one with his trainer, he can take the therapy home. All data is synchronized with the cloud based server, so the therapist knows whether the exercises were done as prescribed.

The VAST.Rehab games are adjusted to the possibilities of the personal mobility device such as : squats and abdomen exercises which makes the training more engaging and fun for the senior. In collaboration with our partners in Zuid Zorg we have already started to test the device with the VAST.Rehab software and received first good opinions from the users.

Cognitive impairment and physical inactivity are linked together in process of ageing. For example, dementia is positively correlated with decreased physical activity, fear of falling and associated pain (**Bherer, 2013**). **Erickson et al**. showed that regular physical exercises effectively reverse hippocampal volume loss which is connected to improved memory function. Accordingly, the personal mobility device which will be created in REACH should tackle both issues. Supporting this statement, numerous evidences suggest a high efficiency of a combination of cerebral and physical training. For example, training of cognitive function in combination with task oriented physical activity can reduce the risk of falls among older adults. Moreover, dual-tasking exercises are considered as a critical health care need for improving balance and gait (**Silsupadol, 2009**).

The multimedia program also effectively supports cognitive processes during physical and mental exercises. ActivLife aim to be an innovative device which, through movements of the body, uses the patient's interactions with games to measure mobility and improve overall physical fitness.

This modern technology can change the lifestyle of the elderly from sedentary to more active. The software contains exercise modules (cognitive, memory, logical thinking, coordination, general improvement) with varying degrees of difficulty. A simple operating system, remote control for changing programs, control system, possibility to use additional accessories – all this allows to use the device at home. ActivLife can be effectively used in intervention programs to reduce the risk of falling among elderly people.

The designed device is under the process of constant development. All the components of personal mobility device which has been described in chapter 3 together with using proper motivational techniques which can be applied for the seniors – described in **section 2.2 of this deliverable** constitute a comprehensive intervention program for decreasing activity among older adults.

Due to the continuous development of all parts of the personal mobility device system, it is necessary to test the equipment among the potential users in order to get the solution well adjusted to the seniors needs.

All the parts of the personal mobility device system need further development to be perfectly adjusted to seniors needs.

According to the testing decomposition approach, the tests were divided into stages.

HUG I: usability test of early mock-up of Touchpoint 1 (usability test under controlled conditions at HUG with 15 elderlies, duration: several hours; test conducted in spring 2017). The test involved AMs mobility device, a gaming approach and wearable sensors. The test served PAD category 1 (mobility, Touchpoint 1) and crossed several SMI testing instances.

Alreh I: usability test of early mock-up of Touchpoint 1 (usability test under controlled conditions at AM with 14 elderlies and test of fall prevention programme based on the device with gaming, duration: several hours; test conducted in summer 2017). The test involved AMs mobility device and a gaming approach. The test served PAD category 1 (mobility, Touchpoint 1) and crossed several SMI testing instances.

Outcomes from both tests were reported in **Gerontechnology Journal Issue 3/2017(October 2017)**.

Based on the results of performed tests, we will further develop the system and adjust it to the possible intervention strategies described in **chapter 1.3 and 2.2. of this deliverable**.

4.1 Touchpoint 1 testing

4.1.1 Case study 1: initial early testing at HUG (user acceptance)

Goals

This study aimed at assessing the safety, validity and functionality of devices that may be adapted for the cluster Touchpoint 1: a rehabilitation equipment produced by Alreh Medical, its software, Neuroforma, and a wearable sensor, the Fitbit Charge 2.

Methodology and procedure

Patients hospitalized at the geriatric division of Geneva University Hospitals and healthy controls were recruited. Patients were randomly assigned to train their transfers with the device and its associated-software, Neuroforma, or according to the Standard Medical Care (SMC) during 4 consecutive days over 30 minutes. Healthy controls trained their transfers using the device and Neuroforma. Exercises were monitored by the Fitbit Charge 2. Safety was assessed by free reporting, functionality by the NASA Task-Load Index (NTLI) and by free commenting by patients and care-givers. Differences between heart rate values measured by the Fitbit device and those measured by care-givers assessed the accuracy of heart rate measurement by the Fitbit device.
We conducted the study with 15 participants: 10 patients and 5 healthy controls. 5 patients followed the SMC, 5 patients used the device with the Neuroforma and 5 healthy participants used the device with the Neuroforma. All of them used the Fitbit Charge 2, during the training, to measure their heart rate. Participants' heartrate was also measured before, during and after each training.

Participants

The inclusion criteria for the patients were: 65 years old, hospitalized at the Geneva geriatric hospital with a planned discharge and who will receive the help of IMAD (Institution Genevoise de Maintien à Domicile) at home, with an MMSE (Mini-Mental State Examination) between 20 and 28 or a FIM (Functional Independence Measure) less than 6. The inclusion criteria for the healthy controls were people aged between 30 and 80 years old with no medical conditions that doesn't allow rehabilitation exercise.
The mean age of patient who were trained following the SMC was 79.8, 3 males and 2 females. Most of them had cardio-vascular and osteo-articular pathology. The mean age of patients who used the device was 89.6, 4 males and 1 female. Most of them had cardio-vascular pathology. The mean age of healthy participants was 42.4, 2 males and 3 females.

Results

a. Quantitative

Validity

Table 4-1: Absolut differences in heart rate measurements between Fitbits and caregivers. n = number of measurements in each group. std = standard deviation and Δ = difference. All measurements are in beats per minute.

	Healthy controls n = 60	SMC Patients n = 48	Alreh device Patients n = 45	Total n = 153
mean |Δ| (std)	11,55 (12,34)	9 (10,16)	8,73 (11,98)	9,92 (11,59)
max |Δ|	48	59	54	59
% |Δ| > 10 bpm	35	31,3	24,4	30,7

Although the mean absolut difference in heart rate measurements between Fitbits and SMC were around 10bpm, the max value of these difference still reached 59 and 30% of the values measured were more than 10bpm. These results raised concerns about the validity of Fitbit for HR measurements. Further investigations are needed to confirm these results.

Functionality

Table 4-2: Mean NTLI scores per item and group. Scale from 1 to 20 with standard deviation reported under parenthesis. SMC = standard medical care.

	Healthy controls using Alreh device	Patients following SMC	Patients using Alreh device
Mental Demand	4 (3,3)	6 (3,4)	4,8 (1,5)
Physical Demand	6,2 (5,5)	14 (2)	16,2 (3,1)
Temporal Demand	9,6 (4,6)	11,6 (1,7)	12,4 (2,3)
Performance	8,6 (6)	6 (1)	7,2 (6,8)
Effort	8,4 (5,5)	15 (5,7)	17,6 (2,2)
Frustration	7,8 (5,6)	4,4 (1,3)	6 (4,8)

Le NASA Task-Load Index showed that the equipment needed more physical and temporal demand as well as more effort from the patients. This is somehow understandable considering the rehabilitation process. However, the global performance should be improved and the frustration while using the equipment should be decreased.

b. Qualitative

Functionality

The caregivers pointed up the ease of use of the device, regarding the mounting and unmounting of the equipment. Although it was not really adapted to lower limbs exercise, it

was very well adapted for squats. It also provides useful trunk stabilization but these cases are rare in hospital settings. The verticalization force were also reported to be too strong and should be adapted. To sum up, device is very suitable for patients with severe limitation in lower limbs and needs to be stabilized to perform upper limbs exercise.
The Neuroforma software associated to the device were reported to have a clear interface and to be easy to use. However, from the caregivers' perspective, the design needs a bit of refreshing. In addition, the patients showed low interest in video games.
The caregivers and the patients both agreed that the Fitbit were easy to use. Although it was sometimes difficult to adapt the wristband, it was somehow comfortable. For them, it was an interesting tool to promote patient empowerment. One suggestion was to add an alarm in case of heart rate irregularities.

Safety

Apart from the fact that the premature wear of the device wheels should be adapted, there were no serous event reported. The safety is checked.

Conclusions

No major safety issues were reported. Functionality assessment by care-givers and patients concluded that the device in its current form is not properly suited for transfer training in this use case but would be more effective in situations requiring strong trunk stabilization such as upper limb exercises or lower limb exercises for patients suffering from severe lower-limb paresia. The verticalisation force was reported as too strong and the range of possible movements too limited. Some patients reported not being interested in associated video game interface and suggestions of design improvements were made. The ease-of-use and comfort of the Fitbit were appreciated but the wristband was reported as difficult to adapt. The comparison of heart rate values raised concerns about the potential use of the Fitbit Charge 2 as a heart rate measurement tool for REACH.

4.1.2 Case study 2: testing among elderly at University of Health Education (user acceptance)

Goals

The aim of the study was to analyze the effectiveness of training using the ActivLife system in women over 60 years of age which have declared difficulties in maintaining the balance of the body.

Methodology and procedure

The study covered a group of 14 women over 65 years of age and was randomly divided into two groups – an experimental group (7 people) and a control group (7 people).
Prior to the program, both groups were tested in terms of fitness. Baropodometric platform measurements were also performed. The measurements were repeated in both groups after 4 weeks. The studies involved fitness attempts, consisting of the Fullerton Functional Fitness Test.

6 fitness attempts were carried out:

- Chair stand (assessment of muscle strength of the lower limbs; number of repetitions);
- Two minute Step Test (assessment of strength; number of RL-LL cycles);
- Up and Go (assessment of agility and dynamic balance, assessment of the risk of falling; walking time).
- Back Scratch Test (assessment of mobility of the upper part of the body; cm);
- Chair sit-and-reach (assessment of the mobility of the lower spine; cm);
- Arm Curl (assessment of muscle strength of the upper limbs; number of repetitions);

Postural stability measurements were carried out with the use of the FreeMedSensor Medica (Italy) stable-metric platform with the FreeStepver software. 1.4.01.2
Measuring protocols were performed while standing with bare feet for approximately 30 seconds: both with eyes open and closed while standing on both feet. For the purposes of analyses and comparison, path distance values of the footprint on the ground (COP), the path area ellipse size of the footprint on the ground (COP), as well as the range of maximum fluctuations were used.

Three fitness attempts (Up and Go, Chair Stand, Two minute step test) and three parameters of balance measurements (indicated above) were selected as the most important aspects in the prevention of falls in the elderly.

For 4 weeks, the experimental group participated in individual activities (exercises), focused on the prevention of falls. The physical activities were carried out with the use of the ActiveLife system (computer software - “Fitness” module and the stander) and the author’s program of 14 exercises. The experimental group participated in a total of 8 training units (one unit lasted 35-40 minutes).

Participants

The study covered a group of 14 women living in a large city, professionally inactive (retired) , reporting problems with maintaining balance, tripping or falling. The women did not participate in organized fitness activities. Detailed characteristics of the experimental and control groups are shown in Table 1 (below).

Table 4-3: Characteristics of the studied group (Σ ± SD)

Data	Experimental group (n=7)	Control group (n=7)
Age (years)	72.5 (±5.4)	73.5 (±4.5)
Body height (cm)	157.6 (±2.5)	158.4 (±5.6)
Body weight (kg)	64.7 (±9.4)	63.8 (±13.4)

Results

Three fitness attempts were carried out in the groups to examine the aspects which are mostly related to falls and tripping. The average results of the selected fitness attempts and measurements on the balance platform in the experimental and control groups have been summarized in Table 2. There were no statistically significant differences between the measurements carried out before and after the 4-week period of exercise. The range of maximum fluctuations increased ($p < 0.05$), in body stability measurements on the stabilometric platform with eyes kept closed, , whereas the path length and the field drawn by that path (ellipse area) did not differ significantly between measurements with eyes open and closed.

Table 4-4: Average ± SD results of fitness attempts and measurements on the platform with eyes open (OO) and closed (OZ), standing on both feet.

Attempt	Experimental group		Control group	
	1st measurement	2nd measurement	1st measurement	2nd measurement
Up&Go (s)	7.08 (±0.62)	6.58 (±0.92)	6.52 (±1.35)	7.59 (±2.84)
Standing up from a chair (n)	14.29 (±1.79)	17.86 (±2.91)	13.71 (±3.25)	15.71 (±3.73)
March in place 2’ (n)	77.43 (±18.98)	83.86 (±21.48)	75.43 (±17.01)	84.86 (±21.54)
Ellipse size (cm^2) OO	92 (±150)	53 (±78)	41 (±32)	38 (±20)
Ellipse size (cm^2) OZ	134 (±164)	97 (±68)	121 (±98)	92 (±69)
Length of path COP (mm) OO	170 (±23)	177 (±33)	171 (±42)	178 (±37)
Length of path COP (mm) OZ	198 (±37)	252 (±88)	225 (±44)	247 (±69)
Max. fluctuations (cm) OO	1.47 (±0.91)	1.09 (±0.37)	1.54 (±0.82)	1.12 (±0.31)
Max. fluctuations (cm) OZ	5.45 (±4.55)	14.78 (±10.22)	10.27 (±9.73)	10.64 (±5.72)

After analysis of both measurements of fitness attempts, a correlations between the individual results in the studied groups can be observed. In the experimental group, one recorded a positive correlation (r=0.769) between the results of attempting the “Two minute step test” and the “Chair Stand” (r=0.850 in the control group). In addition, the experimental group experienced a significantly negative correlation (r=-0.838) between the results of attempting the “Up-and-Go” and the “Chair Stand” (a negative correlation r=-0.856 in the control group).

During analysis of the results of the studies related to balance and selected fitness attempts, relationships between individual parameters can be observed. Table 3 presents the correlation coefficient values (r).

Table 4-5: Correlation coefficients between the footrest path length on the ground (COP) standing on both feet with eyes open and fitness tests - joint analysis for both groups (N=14).

Variable	Path length COP
Two minute step test	-0.610*
Chair sit and reach (left leg)	-0.757*
Chair sit and reach (right leg)	-0.815*
Back scratch test (left hand)	-0.235
Back scratch test (right hand)	-0.421
Chair stand	-0.446
Up and Go	0.719*
Arm Curl (left hand)	-0.572*
Arm Curl (right hand)	-0.483

Body stability values expressed by the length of the footpath on the ground during stabilometric platform measurements correlate significantly with the fitness attempts related to the participants' mobility, i.e. the "Two minute step test", "Chair sit and reach" and "Up and Go".

Conclusions

The results of the study indicate that there is a connection between the combination of balance-oriented physical exercises combined with modern motion-activated multimedia programs; however, attention should be paid to strength exercises.
Considering the constantly growing number of elderly people, it is necessary to develop different solutions and to implement adjusted programs using specialized tools to minimize the risk of falls. The programs should mainly be directed at increasing muscle strength, improving body balance and coordination. Modern methods allow to individually select a program for fall prevention. All types of programs which use gamification may be a great way to prevent falls or help with the rehabilitation process due to a complication caused by falling, as well as be an important motivator in the improvement process.

5. Functioning of the identified intervention strategies in the context of REACH engine

The REACH consortium has based on its initially defined Sensing-Monitoring-Intervention concept outlined in the DoA, as part of the work carried out so far, detailed and took this concept further towards a unique Sensing-Monitoring-Intervention Activity Flow (**Figure 5-20**).

As part of the **Sensing** section physical activity was further detailed as the target condition and categorized into Physical Activity Dimensions (PADs), namely 1) macro-mobility, 2) micro-mobility, 3) socialising and nutrition, and 4) gaming and training. In that context, several early detection regimes were defined were defined such as a) one-off alarm, b) detection of short or long term activities and patterns, c) device integrated automatic early assessment, which can be applied in specific combinations for each PAD. Based on the PAD and the selected early detection regimes, a specific set of sensors which is able to serve the selected condition and detection regime can be selected in a target oriented manner.

Based on the selected sensing strategy, as part of the **Monitoring** section a combination of wearable and ambient sensors is chosen for each PAD (which equal the REACH Touchpoints). The task of the wearable sensors is obtaining uni- or multivariate physiological signals, whereas the ambient sensors supply in an automatic manner context and labelling.

In the Data collation system, the obtained data set are managed and prepared for processing by various analytics methods and algorithm types. Two major types can be distinguished. Analytics type 1 focusses based on machine learning algorithms on the detection and prediction of activities, trends, and behaviour profiles. Analytics type 2 allows based on clustering algorithms on the matching and optimization of behaviour profiles and personalized intervention profiles through clustering algorithms.

In the **Intervention** section, the through the analytics section generated output is used to, to select develop, and or personalize interventions that react on the early detected trends, patterns, or deviations of physical activity with each PAD. In that context sophisticated motivational techniques and engagement strategies are used and tailored towards PADs and individual users and user profiles to create a highly efficient and long lasting behaviour change. Both programmed interventions and device interventions and interaction sin the REACH use case environments are informed, embedded in, and coordinated by the previously by the analytics section identified behaviour change strategy. With each new data set generated the system will learn better what behaviour change strategies and interventions work best for specific persons.

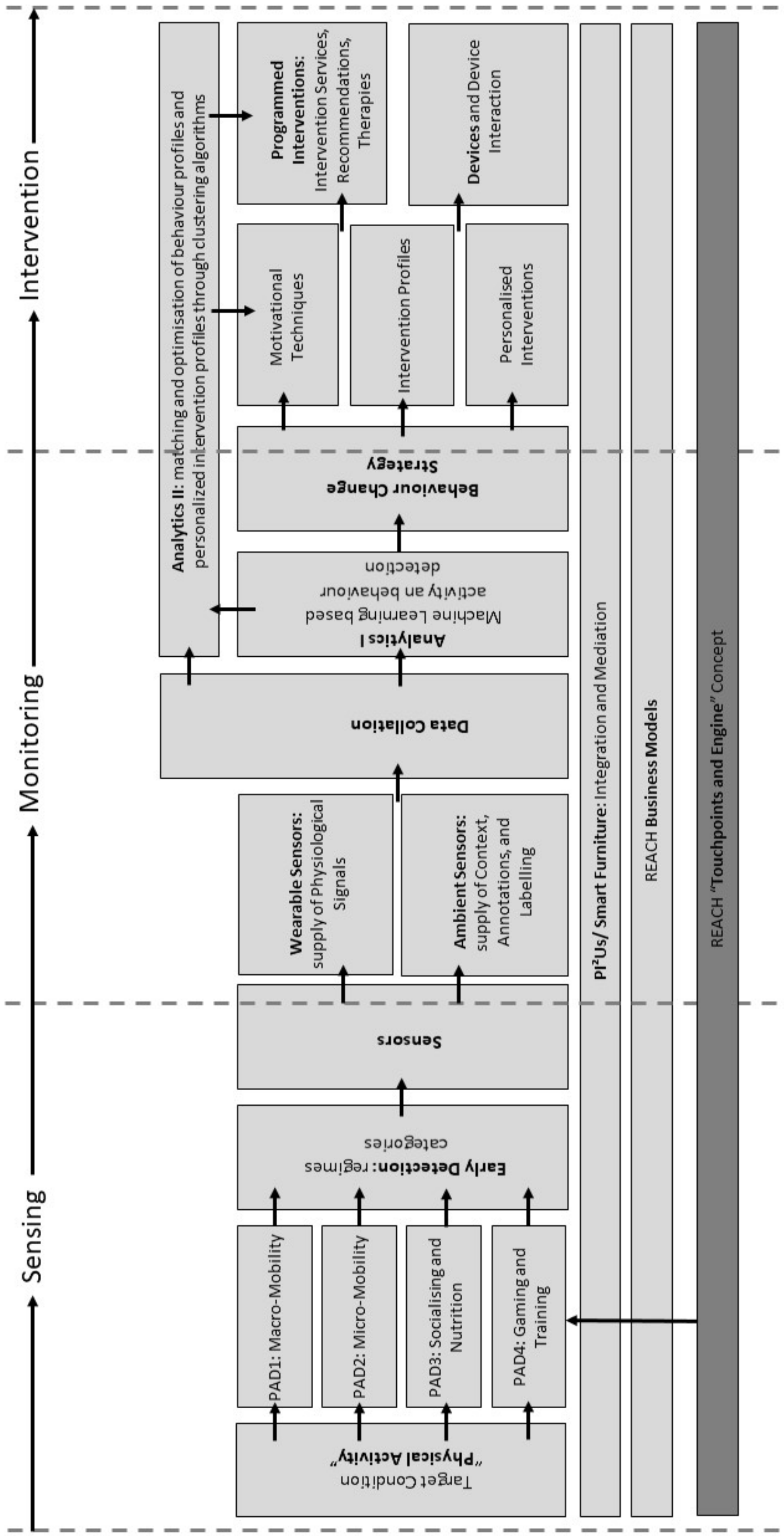


Figure 5-20: **REACH's detailed, unique Sensing-Monitoring-Intervention Activity Flow**

This chain of change is a synthesis of our work, knowledge from the workshops and meetings. During the last Consortium Meeting, which was held in Lyngby in September in a touchpoint-group work with our partners we have developed a scheme of Sensing-Monitoring-Intervention Activity Flow for Touchpoint 1, which is shown on **Figure 5-21**.

Similar scheme was developed for Touchpoint 2 (**Figure 5-22**).

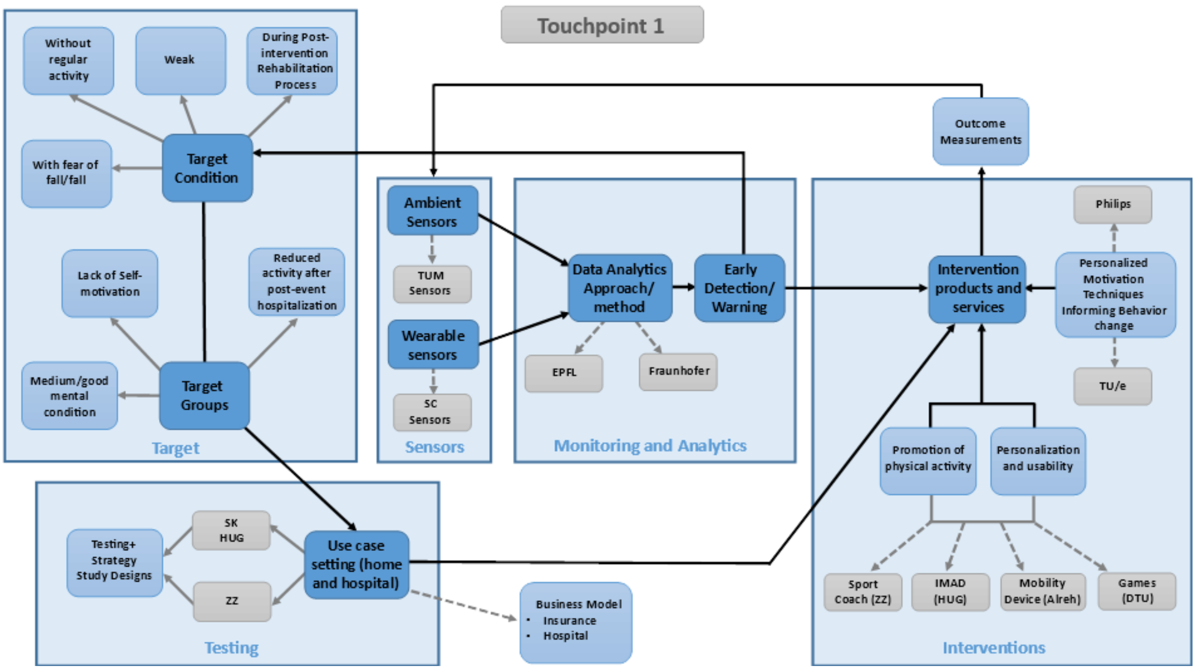


Figure 5-21: **Instantiation of REACH's Sensing-Monitoring-Intervention Activity Flow for Touchpoint 1, Personal Mobility Device (PAD 1: macro mobility, general physical mobility in house and neighborhood)**

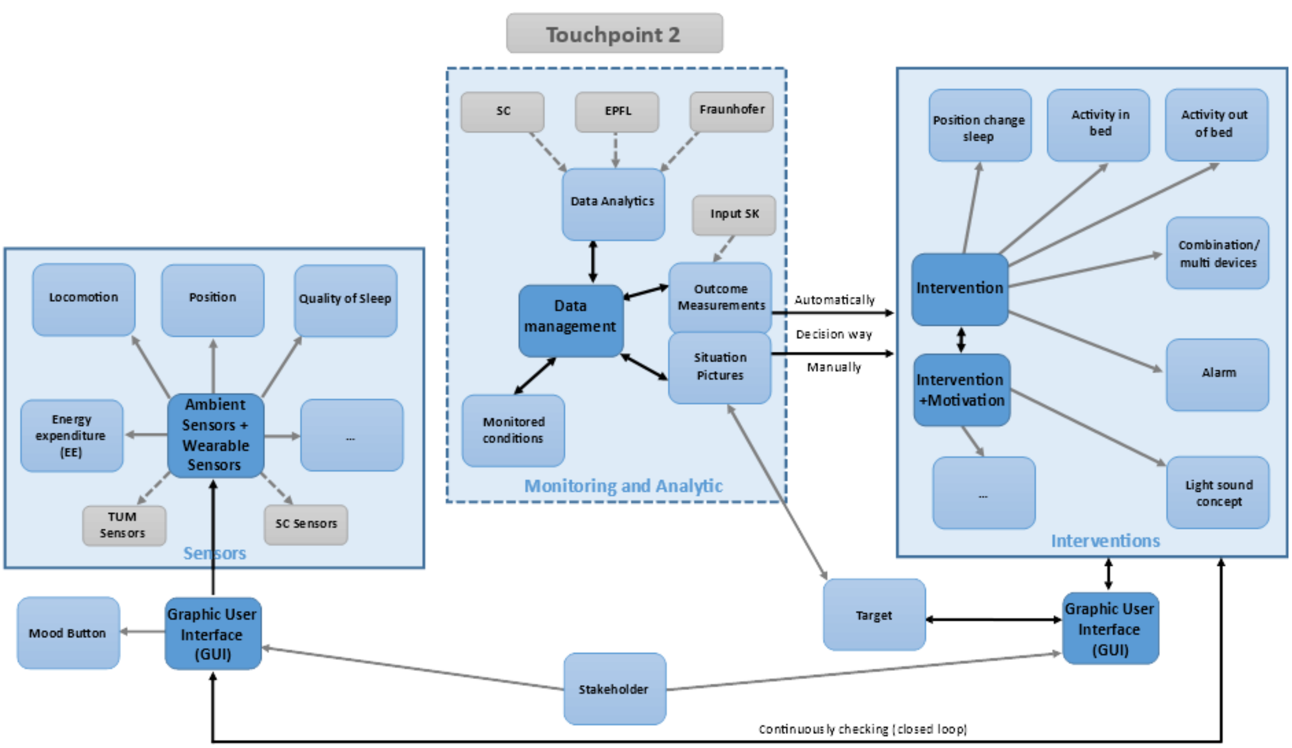


Figure 5-22: Instantiation of REACH's Sensing-Monitoring-Intervention Activity Flow for Touchpoint 2, Touchpoint 2: Active Environment (PAD 2: micro-mobility, postures, and ADL execution)

Based on the knowledge described in previous chapters of this deliverable about what are the “red alerts” of decreasing activity, what to monitor and how to affect the change among older adults by using different motivational strategies to built the effective intervention, we have created 2 different scenarios of implementation the change of change. “Journey from hospital to home” could work as an example in Schon Klinik and HUG, whereas “home-Activity Center” scenario fits the target group of Zuid Zorg and Lyngby.

General requirements of the REACH Engine and its Communication links were discussed and a first system structure was set up. In a first step, the ICT system will be implemented as an ad-hoc, SC based research version that allows to centrally manage and store all data gathering activities and in later project phases cross-links to Philip’s proprietary HSDP will be created.

5.1 Use-case scenarios

5.1.1 Scenario: Journey from hospital to home

Following his cerebral ischemic stroke, Mr. Autumn underwent surgery and had to stay three weeks at the hospital. The first days at the hospital were gloomy. Mr Autumn was afraid to not be able to use the right part of his body anymore. But a few days later, he started to have a light physical session with his physiotherapist. The physiotherapist used REACH equipment to help him **do the exercise** in a **safe setting**, to ensure that he will not fall and to make him confident in being able to do the task. Every day, Mr. Autumn’s **progress** and his **vitals** were **monitored** by the system in **real time**, so that the physiotherapist could help him immediately **adjust the exercise** if needed. In the beginning, the doctors and the nurses came every day to check on his health status and **the evolution of his vital parameters**. He also had a daily session with the physiotherapist using the REACH equipment, where he was assisted while performing the exercise. After a week, Mr. Autumn were asked to **do the exercise alone**, at the hospital, using the equipment. The physiotherapist introduced to him a new way of **exercising while playing a game** on the screen and gave him a **certain score to reach** on the game. As he got used to play the game and do the required exercise, the physiotherapist wanted in a second phase to use the REACH system to **check** whether Mr. Autumn were **doing the exercise correctly** or not. Through the system, Mr. Autumn could **see in real time** if he must repeat or correct a motion. In a third phase, the physiotherapist and the doctors wanted to **see, if** performing the daily exercise **has improved** Mr. Autumn’s **health and autonomy** while staying at the hospital. Through the **history** from the REACH system, they could see that his vitals were more stabilized and that Mr. Autumn became more active. If in the beginning, he was sitting or lying in bed all day, his **intelligent sensors** showed that he is doing a lot more **steps.** The systems also measured his **stress level** to help the doctors see if Mr. Autumn is confident enough to go back and continue the recovery at home.

After three weeks, Mr. Autumn went back home equipped with the REACH system. Although, he was away from the hospital, the doctors and the physiotherapists wanted **to receive** every day, all his **vital parameters**, his **health status** and his **physical activity** during the first days back home, so that the system would **alert** them **if anything** was

abnormal. The system would allow the doctors and the physiotherapists at the hospital and the caregivers who comes every day at Mr. Autumn house to **exchange information** about his **health evolution**. After some days, Mr Autumn was **encouraged** through **different gamification techniques** to use the equipment to do physical exercise in a **safely manner**. All of his activity was **monitored**, **analyzed** and then **transmitted** to his caregivers in order to **detect** a potential **fall** or a **deterioration of his health**. The physiotherapists and the doctors could **congratulate** him through the system when he was following correctly their recommendation. Depending Mr's Autumn's need of care, the system could **notify the corresponding caregivers** who can come and help him if needed. Mr. Autumn's daughter was happy to be able to **follow** her father's **health evolution** through the REACH system. Being able to **check** on his **vitals**, **activity**, **mood,** and **nutrition** in real time, she felt more at ease and less worried when she was not with him.

5.1.2 Scenario: Home – Activity Center

Living alone for 10 years now, Mr Autumn was leading a peaceful life with his dog Woody. He was following a happy daily routine by going shopping, walking his dog in the morning and playing chess with his friends in the afternoon. However, one day, Woody passed away and left Mr Autumn struggling by himself. As there was no dog to walk out anymore, Mr Autumn lost the motivation to go outside and stayed more often at home. After a while, he also stopped visiting his friends for playing chess. Within few weeks, the REACH system **detected a significant decrease** in his activity level and **showed an alert** on the interface. Mr Autumn was detected more often at home and the different **motion sensor** showed that he was **sitting most of the time on the sofa** in the living room or **sleeping all the afternoon in his bed**. When Mr Autumn went out to buy something, which became very rare, it took him more time than before to reach the shop. He felt more exhausted walking. The system also **showed that his heartrate increased** a lot when he was taking the stairs. He was breathless until he reached his apartment. One day, Mr Autumn fell while going to the shop. Nothing serious happened, but since that day, he was afraid to go out because of the fear of falling. He asked a friend, Mr Nurbert, to shop for him. When Mr Nurbert went to deliver the groceries to him, he was worried to see Mr Autumn in a bad condition. Mr Nurbert is often visiting an activity center which is not far from Mr Autumn apartment. He proposed to him to come there to see if would like it. After, multiple debates around the subject, Mr Autumn finally agreed to try it out and went with Mr Nurbert to the activity center.

Various social activity and physical training with a sport coach were proposed to Mr Autumn at the activity center. He immediately chose the chess club. They were also cooking and watching movies together. The sport coach involved Mr Autumn in **a training program with the REACH personal mobility device.** Mr Autumn was happy to **play activity games** while **being safe** inside the device. For the first time, since he lost Woody, he smiled and laughed again. He was **gaining scores** and **trained his mind** at the same time. Mr Autumn wanted to come more often to the activity center to continue the training. Day by day, the sport coach and Mr Autumn **could see** through the system that he **achieved better results**. As he was under the supervision of the sport coach, his **program could be adjusted to his abilities**. Mr Autumn could see with his coach **in real time** his **vital parameters** and the **amount of activity** he has done. At the end of the week, they looked together through his **game scores** to see his **progress.** Mr Autumn **received a lot of praise** from his coach and his new friends at the activity center. He felt more strong and secure. The REACH system installed at his home **could see** that he was **active** and **out of the house** more often. This **report** was **sent** to his **caregivers.** Mr Autumn was happy again to have more friends and to participate in activity which **increased his confidence level**. He is not afraid to go out and to fall anymore.

From the above scenarios, we could identify the different strategies to be involved in each component of the chain.

a) Early detection

The system will learn about the patient's daily life and health parameters, including his/her medical records from his/her stay at the hospital. The decrease of physical activity data and abnormalities in health parameters may help detect ahead of time, the decrease in the patient's health. These data would be continuously monitored while the patient is at home. Information from nurses or caregivers who visits the patient at home will give additional data to allow a more precise detection of any decrease regarding the patient's health.

b) Wearable/ambient sensors

Wearable sensors to measure activity data and health data will be used by the patient at home while doing exercise with the equipment but also while conduction his/her everyday life. Additionally, ambient sensors would give us more detailed information. As an example, a motion sensor would let us know, in which room are the patient more active or inactive, or if no motion at all has been detected for a long period of time.

c) Motivational strategies – Intervention

Upon detecting abnormalities or decrease in physical activity or health, the system should be able to react accordingly and adapt the intervention. In case of decrease in physical activity, the system could for example split the recommended exercise into chunks of exercise to do along the day to motivate the patient. The gaming interface should be adapted to the user's preference. The amount of exercise should follow the patient's ability. In case, his/her health parameters are not good, the system should be able to adapt the recommendation accordingly. The system should also allow occasional interaction with the physiotherapist through the game, so that they can be congratulated when they do the required exercise. Additionally, it should be able to inform the patient, in a very simple manner, the progress he/she has done, to increase his/her motivation. Finally, when detecting abnormalities or decrease, the system should be able to inform the right caregiver depending the situation.

6. Conclusion

One of the most important aspects in early detection measurements is feedback: if it is possible to indicate behavior change among older adults by continuous monitoring.

The way is not to change the whole previous lifestyle but to complement the existing one with new element such as regular physical activity: 20 minutes a day keeps a doctor away!

According to the previously discussed criteria, the most important objectives of developing sensor systems into different PI^2Us is to realize the following requirements:

- Continuous monitoring
- Early detection
- Motivation for more activity
- Prevention
- Timely intervention
- Post intervention monitoring

In the previous sections different aspects of each requirement was discussed in details and solutions and ideas were proposed. All these criteria will create a fundamental change in the lifestyle of elderly citizens leading to avoid two major targets. Firstly, to avoid losing ability to perform Activities of Daily Living and secondly to extend the time period spent in the desirable physical and mental health status.

Table 4-6 provides an overview of PSS concepts based on motivational strategies, per touchpoint Many of these have been named in earlier chapters of this deliverable and in **deliverable D14** .

Table 4-6: Overview of PSS concept based on motivational strategies

Touchpoint	Theme	Early Detection	Application of the motivational strategies	Intervention product service system concept	Functioning of the identified intervention strategies	Implementation of the scenario
Personal mobility device (TP1)	- Falls - Frailty	Signs of frailty. Person under risk of falls. Evolutionary approach: early detection will be done only with the sensors; when then risks of falls or signs of frailty are detected the mobility device comes in as a safe activation and training device. The mobility device optimally follows (and can modularly be adapted to) the person throughout the patient journey through different care stages.	- Gamification - Social incentives - Goal directed behavior -Self – reflection / selfefficacy - Persuasion, - Incentivisation, - Training (virtual coach), - Modelling, - Enablement barriers	The mobility device functions as a kind of medical home or indoor fitness device. A screen and motion sensor allows for an interactive scenario where the users can play games or follow mobility training instructions. Like in a fitness device in a fitness studio, our device should contain some basic (and modularly separable) physiological sensors on board that allow to monitor the training progress and outcomes.	It will monitor the daily activity of the elderly (plus respond accordingly in the event of a fall or progressing inactivity) An individual intervention programme can be quickly implemented to protect the elderly against progressive inactivity (physical activity/personal mobility device) Result: staying at home for as long as possible, protecting against unwanted hospitalization	“**home-Activity Center”** scenario fits the target group of Zuid Zorg and Lyngby
Active environment (TP2)	- Mobility	Early detect and prevent decrease of (micro) mobility in a care environment. Therefore measure/monitor performance levels: positioning problems, balance/falls. Measure/monitor mood: Track mood based on the physiological measurement + track mood by clinical professionals e.g. by depression questionnaire (and correlate/match both).	-Activity engagement in patient and therapy rooms. -Motivate to participate in therapies, training and interventions -Gamafication -Socializing -Motivating the user with concentration on autonomy	A combination and integration of “furniture” components (bed + bed periphery + mobility device (iStander) + toileting support) to a seamless in-house “transfer and mobility chain” should facilitate a significant increase of mobility in the patient room. Both the personal mobility device (TP1) and the Playware tiles based “gaming and training” system (TP4) may later on be used as additional interventions	.The idea here is to detect and prevent decrease of (micro) mobility in a care environment early on. Therefore, performance levels (positioning problems, balance/falls) are measured and monitored. Mood should be tracked in the future as well, both based on the physiological measurement + track mood by clinical professionals e.g. via depression questionnaire (and correlate/match both)	“**Journey from hospital to home”** fits the target group of schÖn Klinik and HUG

A good activation solution must be built on a personal motivation of a senior for change which can be autonomous or (more often) can be created in a social interaction. Most important is how to influence the elderly when an appropriate time for intervention in their life is detected.

A solution by which higher percentage of elderly group switch into higher physical and mental activity against biological and cultural patterns is very difficult to achieve. Our proposed solutions must be tested for effectiveness in the REACH project.

We have already started to test the personal mobility device system in Zuid Zorg meet and greet center. In the first period the usability and user experience tests will be made. First impression of the senior-user was evaluated with the self-made questionnaire. The moderate score (on 5 questions) was 4,2, on a scale 1-5.
In collaboration with the sport coach and our partners from Tu/e we are going to work on personal activation training programme which will be adjusted to the needs and abilities of older adults users.

Figure 5-23: Test of activLife in ZuidZorg activity center

The aim of ongoing tests is to make the prototype more advance. For the next steps, based on what we have learnt from Deliverable D15 we want to work on the implementation of created strategies and use-case scenarios. During the first year of the project, we have just tested the parts of a scheme and there is a need to test the whole integrated chain in a close perspective.

Since the current deliverable (**D15**) reports on ongoing tasks (T4.2 and T4.3: M15-M36), it will be updated in accordance with the progress of work in these tasks.

This deliverable outputs are relevant for working on the development of the PSS (Product-Service System) concept. Only a combination of motivation strategies, proper sensing system and personal mobility device adjusted for the user needs will create the proper intervention which can be applied for the older adults with decreasing life activity to prevent further decline and other adverse outcomes such as falls and disability which is the main goal for the REACH project.

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