A Personalized and Context-Aware Mobile Assistance System for Cardiovascular Prevention and Rehabilitation

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Abstract Existing approaches for personalized regulation and adaptation of physical activity for cardiovascular disease prevention and rehabilitation are often based on one quantitative parameter, usually heart rate. Other influence factors such as time of day, nutritional condition, outside temperature, exhaustion level are ignored and greatly impede an optimal personalization. In the following an innovative mobile assistance system is presented uses electrocardiogram (ECG) records as parameter for personalization (an electrocardiogram is proven to be better parameter for personalization). Moreover a "connected pedelec", i.e. a bicycles equipped with an auxiliary motor which only assists when the cyclist pedals, is used a exercise machine. Thus, for the first time automated regulation and personalized adaptation based on ECG records are made mobile. In addition, a holistic approach is applied which also considers other parameters for the assistance during the exercise but also for the assistance before and after the exercise. As a result a more holistic approach for personalized regulation and adaptation of physical activity and individualized assistance and motivation is provided before and after exercise.

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1 Introduction

Physical activities as a protection against coronary heart disease was firstly examined in the mid-20th century [1]. Further research proved the relationship between physical activity and reduction of risk of mortality and morbidity from cardiovascular disease [2–4]. Andersen et al. conducted a study which links regular bicycling with a decreased risk of mortality [5]. The authors found out that even after adjustment for other risk factors those who did cycle to work had a 39 % lower risk of mortality. Cycling was identified as one of the solutions to improve health [6], since it has a functional role which does not completely rely on self-motivation and thus can contribute to higher levels of physical activity [7]. In addition to the benefits for the environment, transportation research considers increased walking and cycling (together called active transportation [8]) to improve public fitness, particularly for vulnerable populations such as children or seniors [9]. Furthermore, the goal of the European Union (EU) is to phase out conventionally fuelled cars in urban transport by 2050. This shows that cycling will play a major role as shaping means of future transportation.

The growing public awareness of the health benefits and of the advantages of cycling to solve mobility problems is also reflected in the growing market for electric power assisted cycles (EPAC). EPACs cover two different concepts of bicycles with an auxiliary electric motor [10]:

- Cycles equipped with an auxiliary motor that cannot be exclusively propelled by that motor. Only when the cyclist pedals, does the motor assist. These vehicles are generally called 'pedelecs' short for "pedal electric cycle" and they are today the most popular in the EU.
- Cycles equipped with an auxiliary electric motor that can be exclusively propelled by that motor. The cyclist is not necessarily required to pedal. These vehicles are generally called 'E-bikes'.

In terms of physical activity pedelecs are of greater interest than E-bikes, since motor assistance requires pedaling. There are different levels of motor assistance which can be set by the cyclist. Latest pedelec models provide a mobile app to adjust the assistance level, i.e. a mobile phone instead of the integrated control unit is attached to the rod and sends commands about the assistance level to the motor. In view of the rapid growth of the mobile broadband market worldwide ("Mobile broadband has become the single most dynamic ICT service reaching a 40 % annual subscription growth in 2011." [11]) the integration of a smart phone provides the possibility of a "connected pedelec". Connection on the one hand allows the collection of information about the user and the user's context, since different information sources such as motor, external sensors (e.g. electrocardiogram monitoring device, SO2 sensor, respiratory rate sensor) and smart phone sensors (e.g. GPS or accelerometer) can be connected to the smart phone. On the other hand, the mobile internet connection of the smart phone allows for the transmission of the collected information to a server which is able to process and analyse the collected information.

2 Motivation

Recording of vital signs and their analysis in real-time for personalized regulation and adaptation of exercise for cardiovascular disease prevention and rehabilitation is possible only to a limited extent. Existing approaches in therapy or prevention are often very vague, e.g. recommendation such as “running without heavy breathing” or individual perception of exertion are usually given to a patient. In other approaches personalization mechanisms are based on quantitative parameters such as heart rate. The maximum heart is often used in training or rehabilitation plans as a threshold which must not be exceeded during the exercise. A common approach to determine the maximum heart rate is the equation: $HRmax = 220-age$ [12]. However, Robgers [13] showed that origin as well as usage of this equation is very questionable from a point of view of sport medicine and sport science. In general, all of the approaches applied today only consider one parameter to individually regulate and control physical activity for cardiovascular rehabilitation and prevention. As a result, influence factors such as time of day, nutritional condition, prescription drug use, effects of substances such caffeine or beta blocker, outside temperature, exhaustion, etc. are ignored and greatly impede an optimal personalization. There are several studies that show that for individualized regulation and adaptation of physical activities the best parameter is the electrocardiogram (ECG) [14–16]. Currently using ECG for personalization is only possible in inpatient treatment. To achieve a regulated physical activity of a patient, exercise on an ergometric bicycle is medical standard in rehabilitation centers. But even there, the power of the ergonometric bicycle is automatically adapted to not exceed a predefined heart rate. The recorded ECG is manually analysed by a physician afterwards and thus not considered in the regulation and control of the physical activity. In this context a connected pedelec which records an ECG and transfers that information and other context information of a user to a backend server for real-time analysis is an approach which neither exists for prevention nor for rehabilitation of cardiovascular diseases. In the following, Sect. 3 looks into existing approaches in industry and research. Section 4 describes our approach named MENTORbike which beside automated adaptation based on ECG data during exercise also looks into assistance and motivation of a user before and after exercise. In this section a use case scenario and the system architecture of MENTOR bike are detailed. The paper finishes with a conclusion and an outlook in Sect. 5

3 Related Work

3.1 Applications of Connected Pedelecs for Health Applications

The German company MTB Cycletec equipped its pedelec e-Jalopy with a new motor called Greenwheel which was developed by the Massachusetts Institute of Technology (MIT). Greenwheel combines for the first time battery, motor and control system in a rear wheel hub motor. Furthermore, a smart phone provides the interface to the Greenwheel motor. It is envisioned that the e-Jalopy will be connected via the smart phone to social networks and with other road users, be located via the GPS integrated in the smart phone and be able to measure pollution and recommend alternate less polluted routes in the future [17]. The Hungarian company Gepida developed an Apple and Android app which enables a cyclist to control the pedelec via his/her smart phone. The app displays information on current, maximum and average speed, daily and total covered distance as well as information on the charge status of the battery and the current assistance level. Via GPS tracking the route can be shown on google maps. Furthermore a heart rate belt can be connected via bluetooth to the smart phone which then can also display the current heart rate and save it. Measured heart rate and other collected information can be sent to medical professionals for analysis afterwards or for real-time monitoring. In addition, the user can specify an upper and lower boundary for the heart rate at which motor assistance is switched on or off automatically [18]. Also the German company Kalkhoff offers automated motor assistance based on an upper and lower heart rate threshold [19].

In summary, pulse control of motor assistance as well as transfer of monitored information to medical professionals are basic assistance mechanisms to support individual health prevention. However, the described approaches are mainly focused on assistance during a ride and do not take an holistic approach for personalized assistance. In the following research approaches for intelligent and mobile assistance systems for personalized prevention and rehabilitation from cardiovascular disease are analysed.

3.2 Mobile Assistance Systems for Cardiovascular Prevention and Rehabilitation

Research on mobile assistance systems for cardiovascular applications can be differentiated into prevention and rehabilitation application.

Ho [20] describes a mobile assistance system for prevention. It generates recommendations during exercise based on the monitored heart rate and exercise intensity. In addition the system can detect anomalies such as incidences of cardiac arrhythmia. Over- or under-exercising is monitored on the mobile handheld. Further evaluations are conducted on a server. Based on collaborative filtering approaches the system determines whether the exercise is suitable or should be adjusted or replaced with another routine.

There are also examples of assistance system for general health prevention and improved life style management or for better life style management such as weight or stress reduction which also contribute to prevention of cardiovascular diseases [21]. However, since they are not particularly focused on cardiovascular topics, they are not further detailed.

Gay et al. [22] describe a mobile assistance system for rehabilitation from cardiovascular diseases. They combine activity and bio signal monitoring (e.g. exercise, ECG, weight, blood pressure, glucose) to generate immediate local feedback to the user without the intervention of a health professional. In addition health professionals can access the user's data and carry out remote monitoring and reporting. Furthermore, the system can detect emergencies such as life-threatening cardiac arrhythmia or a fall and issue an emergency call. Immediate feedback comprises information about over- or under-exercise based on heart rate information. Mainly the system assists with the management of exercise and active (via questionnaires) and passive monitoring (recording of vital signs) of the health status. Deeper analysis of the data is expected from the medical professionals.

The research project HeartCycle develops amongst others personalized mobile assistance system for exercise for users who suffered from heart failure and coronary heart disease. The user is equipped with an exercise shirt that collects the user's vital signs during the exercise. These are transmitted in real-time to a portable station (PDA) which also contains the training plan. The PDA processes the collected data and provides feedback to the patient during the training based on the training plan. At home the PDA is connected to a PC which conducts progress analysis based on the latest information [23].

Similar to Sect. 3.1, the described examples are focused on basic feedback during physical activity, monitoring and data transfer to medical professionals. Feedback during physical activity is even more limited since the user is only notified and no automated adaption is possible due to the fact that the exercise machine is not connected. Thus, a connected pedelec provides additional benefits due to the possibility of automated adaptation.

Improved communication with professionals and peers was a common goal throughout the examples described above. Therefore, social networks for health applications are examined in the following section.

3.3 Social Health Networks for Health Applications

Collaboration, flexibility, a pre-eminence of content creation over content consumption and interactivity are considered the most prominent features of the social web [24]. In this context, Barsky et al. [25] consider amongst others wikis, blogs, and the user comment functionality as social networking enabled technologies relevant in the context of health application. For instance, the website British Medical Journal Rapid Responses [26] and an user comment functionality at the website Patient.co.uk [27] offer the opportunity to record your experience as a patient. At Patient.co.uk a user can even rate the experience entries of others, thus extending the peer rating functionality with a reputation management system. In terms of wikis, wikisurgery [28] is an example of a social networking enabled technology which aims at collaboratively building a surgical encyclopedia for surgeons and patients. Examples of health related blogs are DrugScope DrugData Update blog [29]. In terms of social networking sites, LibraryThing Medicine Group [30] is an interesting example, where users with an interest in books about medicine and medical science share content and ideas.

An example of a social community offering several social web enabled technologies is the mental health social network HealthyPlace [31]. Boulos et al. [24] list several more examples of social networking enabled technologies in terms of health applications for instant messaging and virtual meetings or online social gaming. Eysenbach et al. [32] conducted a review of studies on health related virtual communities and support groups and their effects of online peer to peer interactions. The results lead to the conclusion that no robust evidence exists on the effects on health and social outcomes of computer based peer to peer communities and electronic self support groups. Eysenbach et al. [32] point out that due to the growing number of virtual communities and support groups more quantitative studies are needed in addition to qualitative studies on this topic.

An American study on social media and health conducted by the Pew Internet & American Life Project [33] found out that collaborative filtering mechanisms of the social web are a main feature users look for when using web 2.0 technologies, since they search for “just-in-time-someone-like-me”. On the other hand creation of health content is rather low compared to the consumption of health content. The survey furthermore found out that social networking sites are used only sparingly for health queries and updates and that there is a surge of interest in information about exercise and fitness. Overall, social health networks are mainly designed to get information about health topics from professionals. Quality is ensured since information is provided and supervised by professionals. However, information is usually more general and more suitable to get a general understanding of a health issue. Information about a particular health situation or issue is more likely to be found when individual describe their experiences which is mostly via blogs. However, in this context information sources are usually laypersons, so that quality and thus usability of the information is questionable. A combination of information sources consisting of laypersons with similar experiences (i.e. using collaborative experiences) and professionals promises to improve the quality of social health networks.

4 A Personalized and Context-Aware Mobile Assistance System for Cardiovascular Prevention and Rehabilitation

The approaches described in Sect. 2 were mainly focused on assistance during physical activity. However, a holistic approach should support and motivate a user before and after physical activity as well and connect the user with peers and professionals. Therefore, in the following a system is described which comprises a connected pedelec. The system called MENTORbike consists of the following components:

- Connected pedelec
- Wireless body area network
- Sensing system (e.g. mobile electrocardiogram monitoring device, GPS, pedelec motor)
- Central service platform on a backend server.

The smart phone connects the pedelec on the one hand with the wireless body area network and smart phone acts as data collecting and processing device. On the other the smart phone is connected to the mobile internet and transfers the collected data to the service platform on the backend sever.

4.1 Use Case Scenarios

MENTORbike provides great benefits in transitional situations in rehabilitation and for motivational aspects in prevention of cardiovascular diseases.

In rehabilitation the fact that the pedelec is a connected exercise device and thus can be adapted automatically makes it possible to take monitored and regulated exercise outside for the first time. Duration of training, power in Watt and maximum heart rate with which a patient should exercise are indicated in a rehabilitation plan. In order to set a fixed power level usually ergonomic stationary bicycles are used. In addition, the patient's heart rate is monitored during the exercise by a physician who can intervene if the heart rate exceeds the prescribed limit. With the connected pedelec adjustment of power and heart rate monitoring can be automated and taken safely outside. The patient can start exercising with a fixed connected pedelec inside where he/she can get used to the automated adaptation of power, heart rate monitoring and the user interface of the smart phone. When the user feels secure and strong enough, the connected pedelec can be taken outside for rehabilitation exercise. Thus, the patient greatly benefits in the transitional phase from inside to outside training or exercise at home. Moreover, patients with different rehabilitation plans can cycle together with a trainer. Vital parameters of the members of the exercise group are transferred to the trainer's smart phone. The system alerts the trainer based on the individual rehabilitation plans when there are deviations from the plan.

In prevention the transition between stationary and mobile usage greatly benefits the motivation of a user. In case of bad weather training can be conducted and monitored inside. For outside training the connected service platform can provide mobile services based on the user's context in addition to the automated adaptation of the motor. For instance, location-based services such as the next bus station to go home due to the fact that the user over-exercised, or next resting points (e.g. a restaurant or cafe) can be provided based on the monitored user situation. Furthermore, similar to the rehabilitation scenario the pedelec enables cycling in a group with different fitness level. This community aspect is transferred from real to virtual world by offering a MENTORbike social network. Following the conclusions from Sect. 2.3 this social network will provide the opportunity of communication and information exchange with health professionals and peers. A user will be able to give physicians, trainers, etc. access to collected data. Based on for instance the recorded ECG, a physician will be able to conduct long-term monitoring of the training progress and its effects on the user's heart. A trainer will be able to for instance to improve the training plan based on the monitored progress. Furthermore, the user will be able to post the routes he cycled, set up training meetings, etc. Here, the system can recommended for instance suitable training partners based on similar fitness level or or provide a user with suitable cycling routes which match his/her route profile. Also access to suitable services such as diet plans or services about cycling and health topics can be better recommended to a user based a user profile which a user specifies in the beginning but will be also learned by the system from the monitored user interactions.

4.2 System Architecture

Figure 1 depicts the architecture of MENTORbike fun which aims at assistance with prevention of cardiovascular disease. The system consists of a mobile side and a server side. The mobile side contains all external sensors from ECG device and pedelec and additional sensors such as blood pressure and oxygen saturation sensor. With the pedelec sensors the exact amount of power applied by user and the exact amount of power added by the motor can be determined. With the additional information from the ECG device on heart rate and ECG and further information from external sensors much more detailed analysis about the training can be conducted and as a result also an improved personalization is possible.

The smart phone contains internal sensors such as GPS or acceleration and the mobile MENTORbike app. The mobile app controls the pedelec motor based on the collected context information of the user which is partly processed on the smart phone in the application logic component. Furthermore, the smart phone sends the collected information and evaluation results to the MENTORbike server side. The service platform serves as a single entry point and the interaction facade decides what actions to pursue. Via the push notification component on the service platform the smart phone can be addressed from the server side. Also external services

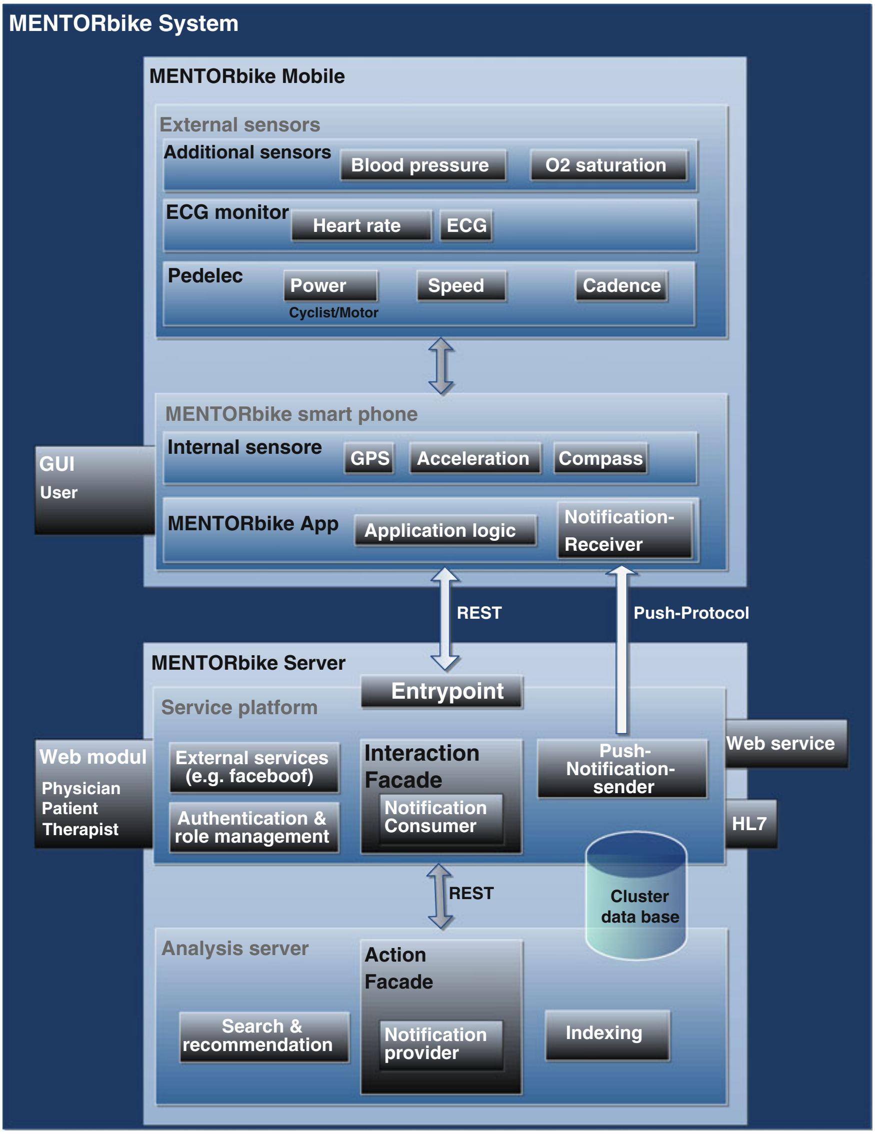

Fig. 1 Architecture MENTORbike fun

such as facebook or google+ are connected to the service platform. Other web services such as bus schedule, location-based services, etc. can be integrated via the web service interface. HL7 interface provides the connection to the medical information system of a hospital or the physician. The web modul enables the user to access his data and the virtual community via a PC, since in MENTORbike cross-modal access to the MENTORbike is envisioned. Also it provides an

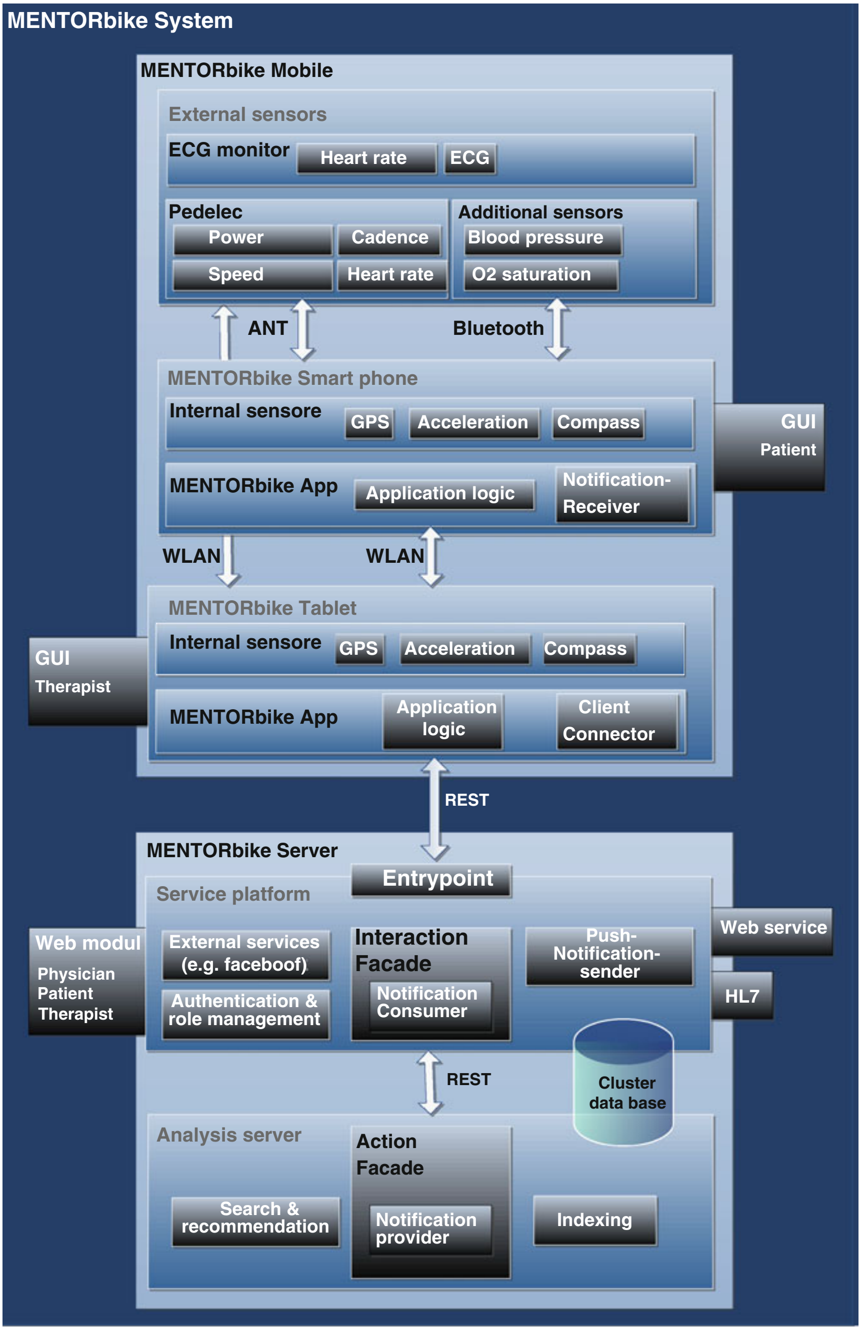

Fig. 2 Architecture MENTORbike Reha

interface for medical professionals to access the collected information of their patients. The authentication and role management component ensure security and privacy of the collected data and data exchange and access. Extensive analysis of the collected data is conducted on the analysis server. Here, the action facade provides the REST interface to the service platform for data exchange and decides how to process the received data. The search and recommendation component contains mechanisms such Bayesian networks for context analysis and content-based and collaborative recommendation mechanisms to detect suitable recommendation objects (e.g. services, training plans, training partners, etc.) for a user. The indexing component contains a semantic knowledge base and a semantic index of recommendation objects. A hybrid search and recommendation approach is envisioned based on traditional and semantic mechanisms. The cluster data base saves and manages the collected information about all users.

Figure 2 depicts the architecture of MENTORbike Reha which aims at assistance with rehabilitation of cardiovascular diseases. The difference to the architecture of the MENTORbike fun is the integration of another mobile device. For the monitored exercise scenario in a group outside with a therapist, the therapists tablet to monitor patients' vital signs is included. As a result, the user interface of the patients' smart phone is much simple than for the MENTORbike fun. Since the user is monitored by a medical professional, only basic information such as heart rate, speed or current position on a map are depicted.

5 Conclusion and Outlook

The paper describes a intelligent and connected pedelec which assist a user with the prevention of cardiovascular disease and the rehabilitation from it. The great advantage of the connected pedelec is the application of electrocardiogram (ECG) for the individualized adaptation instead of the heart rate. Furthermore, the pedelec enables an automated adaptation based on ECG records outside. Also a more detailed monitoring of applied power of the user and added power by the motor compared to stationary ergometric bicycles is possible. The possibility to connect further sensor transforms MENTORbike into a assistance systems which considers much user information than existing systems. The service platform provides the assistance and motivation also before and after exercise and support a user with the management of further activities in addition to exercise for the prevention of or rehabilitation from cardiovascular diseases.

The next steps are first user evaluation via questionnaires and system demonstrators to get feedback about user interface and functionalities at an early development stage of the system.

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