A Conceptual Architecture for an ICT-based Personal Health System for Cardiac Rehabilitation

Completed Research Paper

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ABSTRACT

Traditional cardiac rehabilitation is strongly based on supervised exercise therapy. However, studies show that after leaving a rehabilitative care facility it is difficult for cardiac patients to continue with exercise therapy and overall to conduct the necessary behavioral changes for a healthier life. The novel approach for cardiac rehabilitation presented in this paper is based on including health services (e.g. exercise, support with healthy behavior, etc.) in everyday life. One goal is to foster physical activities which are not solely conducted with the goal to exercise. Another goal is to provide personalized and context-aware health services which proactively assist patients with their disease management. Therefore, a conceptual architecture of an ICT-based personal health system is presented in this paper. The goal is a better alignment with the individual needs of patients and the inclusion of life-long disease management into daily life.

Keywords

Lifestyle-oriented exercise therapy, cardiac rehabilitation, personal health system

INTRODUCTION

Structured exercise-based cardiac rehabilitation programs have shown to be an effective approach to reduce mortality and morbidity in patients suffering from cardiovascular diseases (Binder, Wonisch, Corra, Cohen-Solal, Vanhees, Saner and Schmid, 2008). There are three recognized phases of traditional cardiac rehabilitation. Early mobilization during in-patient treatment at the hospital is considered phase I. Structured and monitored exercise during in-patient and out-patient treatment in a rehabilitation center is phase II and preservation of lifestyle modification is called phase III (Goble and Worcester, 1999). Phase III requires self management to maintain regular physical activity. There are several studies showing that the maintenance of physical activity decreases in the transition from phase II to III and after completion of phase III. Approaches to tackle this issue range from longer phase II participation and specific maintenance programs in phase III (Bock et al. 2003), increased supervision during exercise (Tenenbaum, Freimark, Ahron, Koren-Morag, Schwamenthal, Fisman, Shechter, Tanne, Kachlon, Motro and Adler, 2006) by applying tele-monitoring (Marios, Dalton and Smart, 2012), an improved coordination and cooperation of the network of care takers as well as adaption to individual requirements of a patient (Keck, 2000). However, no holistic approach has been developed so far which provides personalized and context-aware assistance when transitioning from phase II to phase III as well as in phase III and beyond phase III.

The goal of this paper is to provide a holistic conceptual framework for such a system based on the concepts of personal health systems and lifestyle oriented exercise programs following a design-oriented research methodology (cf. Hevner, March, Park and Ram, 2004). At first a description and analysis of traditional cardiac rehabilitation is provided. Based on the identified shortcomings a novel conceptual approach based on a conceptual architecture of an ICT-based system which overcomes the detected shortcomings of traditional cardiac rehabilitation is outlined. This concept will serve as a basis for future research to provide prototypical implementations and evaluations in clinical field tests. Thereafter, related approaches are described and the paper concludes with a summary and an outlook.

ANALYSIS OF TRADITIONAL CARDIAC REHABILITATION

Based on interviews with medical professionals and interviews with patients the traditional cardiac rehabilitation in phase II, phase III and the phase of life-long disease management was identified. The description is provided in the following.

In phase II exercise is monitored and tailored to a patient to provide the most accurate and personalized way to treat a heart condition with a predefined and controlled physical activity (Lewis and Short, 2010). In this context exercise on a stationary exercise machine in combination with a simultaneously conducted and monitored electrocardiogram (ECG) is the core of traditional cardiac rehabilitation (Kligfield and Lauer, 2006). A training plan contains the maximum heart rate of a patient which must not be exceeded during exercise and the amount of power given in Watt the patient has to perform on the ergometer. Both parameters are defined by a doctor and handed over to a therapist who conducts the training with a group of patients. The patients are connected to ECG units and exercise on stationary adaptable exercise machines (e.g. cycle ergometer or rowing machines) while the therapist monitors the patient, i.e. the patient's ECG, heart rate, appearance during exercise, etc. and interferes, if there is an aberration. Based on the maximum heart rate the ergometer automatically adapts resistance, so that the patient's heart rate does not exceed the maximum heart rate. After a few training sessions the therapist is able to derive an individual training heart rate for a patient. In addition to exercising below the maximum heart rate the ergometer can also ensure exercising with a certain training heart rate, i.e. given the training heart rate the ergometer makes sure that the actual heart rates deviates only 10 percent from the defined training heart rate. This type of training is also called pulse-steady-state training. The same applies for the parameter "performed power" of a patient. Given a nominal value for performed power the ergometer ensures that the actual performed power of a patient differs only by 10 percent in total from the defined value. Overall, maximum heart rate is a safety value which must not be exceeded; training heart rate is a variable value which is adapted by the therapist based on a patient's exercise progress. In addition to the described stationary setting, heart patients who are in an advanced state of phase II also take outdoor walks in groups with a therapist who occasionally checks their heart rate manually during the walk.

Phase III is focused on aftercare at home. In so called cardiac outpatients groups participants are taught self-management of their disease. A general practitioner has to refer a patient to a cardiac outpatient group, defining the necessity of the participation and the number of sessions they should attend. Usually the involvement of the general practitioner ends with this referral, i.e. updates about the progress in the outpatient groups only reach the general practitioner during the occasional visits of the patient. In addition to this a patient needs several medical documents: a current examination finding which describes the diagnosis, a recent physical stress test (usually performed on a cycle ergometer), results of the echocardiogram, report of the rehabilitation center and the approval of participation of the health insurance. The required documents are usually collected by patients themselves. A training session is usually led by a therapist with a special training (similar to phase II). In addition nutritional counseling or teaching of stress management techniques are amongst others services provided by the therapist. Furthermore, exercise therapy is of major importance. Outdoor as well as indoor activities such as aerobics, gymnastics, training on fitness devices or walking, jogging, bicycling are carried out. Similar to phase II a pulse-steady-state training supervised by the therapist is conducted. However, participants have to control their pulse and adapt the exercise intensity by themselves, i.e. usually no training devices are available which adapt automatically. Similar to phase II the therapist is present throughout the complete exercise unit to supervise the participants. However, no centralized sensor-based monitoring like in phase II is available. The therapist observes each participant during exercise, asks them how they feel and checks the heart rate if necessary. Once the number of sessions prescribed by the general practitioner is spent, patients have to continue on their own with exercising and hopefully apply the lessons learned about a healthy diet and stress management. The progress and impact of the participation in a cardiac outpatient group is not directly measured.

Based on the description the following attributes were derived for a description framework of traditional cardiac rehabilitation phase II, phase III and beyond phase III called life-long disease management. Attributes and their respective values for phase II, phase III and life-long disease management are listed in table 1.

Traditional cardiac rehabilitation analysis of shortcoming

In the following an analysis of the traditional cardiac rehabilitation based on the description framework and some interviews with therapist, patients and medical professionals is conducted and shortcomings are identified.

Monitoring of exercise therapy includes *sensor-based monitoring* and *in-person monitoring* by medical professionals. Self-monitoring is not particularly listed, since patients are in a fragile state after experiencing a life threat and thus, first have to learn to read their body signs and symptoms correctly again (Piotrowicz and Piotrowicz, 2011). Therefore, monitoring always includes self-monitoring with the verification of external monitoring which can be sensor-based and/or by medical professionals. Self-monitoring in phase III and after phase III is always subjective and prone to perceptive error, so that human or sensor-based monitoring is considered to offer great support to cardiac patients (Marios et al., 2012). It can be noted that the availability of monitoring by medical professionals and sensors decreases throughout the rehabilitation process. Furthermore **rehabilitation progress analysis** is conducted in phase II and III in real-time (*synchronous*) and non-real-time (*asynchronous*). Beyond phase III only asynchronous progress analysis is available. This correlates with the **available patient data**. *Training data* such as average training heart rate, performed power, stress ECG, duration of training are mostly available only in phase II (however, only partly, because as described above, ECG recordings are not saved for further long-term evaluations).

Attributes	**Phase II**	**Phase III**	**Life-long disease management**
Setting of exercise therapy	Mainly indoor	Indoor / Outdoor	Indoor / Outdoor
Monitoring of exercise therapy	Sensor-based (ECG / Heart rate) In-person during training session	Sensor-based (Heart rate) In-person during training session No monitoring outside of training session	No monitoring
Rehabilitation progress analysis	Synchronous by physiotherapist Asynchronous by cardiologist	Synchronous by therapist Asynchronous by general practitioner	Asynchronous by general practitioner
Available patient data	Training data Data from medical exams	Data from medical exams	Data from medical exams
Automatically adapted training	Available	Not available	Not available
Involved parties	Rehabilitation professionals	Exercise therapy therapist General practitioner	General practitioner
Additionally available health services	Medical services Disease management services	Disease management services Behavioral change services	Medical services

Table 1. Description Framework And Values For Traditional Cardiac Rehabilitation Phase II, Phase III and Life-Long Disease Management

A major shortcoming mentioned during the interviews in terms of rehabilitation progress analysis is the little amount of parameters which are considered. Merely, ECG and heart rate and later only heart rate are considered. *Patient data* which is the traditional data from different medical exams such as blood test, ultrasounds, etc. is available throughout the full process; however, the number decreases from phase II to life-long disease management. In this context, the major shortcoming is the fact, that no standardized data management is available for the transfer from phase II to phase III. In summary, there are too little parameters considered, training data is not fully documented, and there is no standardized transfer of data from medical exams.

Overall, the possibility to exercise both *indoor* and *outdoor* in phase III and after phase III (see **setting of exercise training**) is considered an improvement to phase II, since more variability in training setting accounts for a higher degree of motivation to exercise and a good transfer to regular life, which takes place indoors and outdoors (Smart, Haluska, Jeffries and Marwick, 2005). However, this particular improvement of having the opportunity to exercise indoors and outdoors is diminished by the fact, that with the beginning of phase III no automatically adapted training is available (see **automatically adapted training**). The intensity of exercise can always be adapted by patients themselves, however faced with a life-threatening experience such as a heart attack; many patients have difficulties to assess a suitable level of exercise intensity. As a result, they tend to “under-exercise” or to not exercise at all due to fear and insecurity (Kouidi, Farmakiotis, Kouidis and Deligiannis, 2006). Automatically adapted training in phase III and beyond is believed to improve adherence to exercise training and quality of exercise due to a higher level of perceived security of the patient and an improved tailoring of exercise to a patient’s current situation.

In terms of **involved parties**, the number of medical professionals decreases from phase II to life-long disease management. The medical professionals in phase II are many different professionals for rehabilitation, i.e. *rehabilitation professionals*, such as cardiologists, psychologists, physiotherapist, nurse or ECG technicians. Since they are all at one location, the exchange of medical reports can be handled via the hospital information systems. However, it was mentioned during the interviews, that ECG recordings are not saved and only used for real-time monitoring. Therefore, no long-term analysis of ECG recording is possible. When transferring to phase III a patient usually is handed over a medical report for the *general practitioner*. The report represents a summary of the treatment at the rehabilitation center and mostly provides the current health status of the patient. Potentially important recovery progress information is lost. Information transfer is mostly paper based including the medical report, laboratory test results and maybe X-ray photographs. Overall, the information transfer is dependent on the individual medical professionals, i.e. is not standardized. In phase III the patient has to gather different documents from several parties. Data transfer from general practitioner to *therapist* of cardiac outpatient group is often limited to the referral. The therapist conducts a stress cardiopulmonary exercise test and based on the results starts the exercise therapy with the patient.

In terms of **additionally available health services**, *medical services*, *disease management services* and *behavioral change services* were identified as values for this attribute. Medical services include all services related to medical exams such as laboratory blood tests, chest X-ray, echocardiography, six-minute walk test, cardiopulmonary exercise test, etc. Disease management services are services which for instance show the patient how to measure vital parameters, e. g. heart rate or blood pressure, how to perform exercise training, how to self-evaluate symptoms or perceived exertion. Behavioral change services are for instance nutritional education programs or courses on stress management. Overall the number of medical services decreases from phase II to life-long disease management. This correlates with decrease of the number of involved parties. Since patients should improve their health over the course of in-patient rehabilitation to life-long disease management, the decrease of medical exams and involved medical professionals is not surprising. Beyond phase III merely regular check-ups due to the occurred cardiac event are conducted to make sure the condition did not deteriorate. Disease management services and behavioral change services are merely available in phase II and III. Both types of services are educational services to teach patients how to manage their disease or change to a healthier behavior. However, no support or assistance is provided during the implementation of the acquired knowledge. With no or very little feedback, patients tend to forget about the necessary changes or apply them wrongly (Piotrowicz, Baranowski, Bilinska, Stepnowska, Piotrowska, Wojcik, Korewicki, Chojnowska, Malek, Klopotowski, Piotrowski and Piotrowicz, 2010).

A NOVEL CONCEPT FOR CARDIAC REHABILITATION

Basic concepts

The novel approach for cardiac rehabilitation described in the following is based on the concept of personal health systems (PHS) and the concept of lifestyle oriented exercise programs. The former assists in the provision of continuous, quality controlled, and personalized health services regardless of location. One of the main aspects is context recognition which includes recognition of physiological parameters (e.g. vital signs) as well as other health related parameters (e.g. current activity, emotional or social state, and environment). So, on the one hand personal health systems require an infrastructure to gather the necessary information, on the other methods are required to interpret the collected data correctly. Based on the recognized context, PHS provide active feedback to assist in rehabilitation, disease prevention and lifestyle management (Codagnone, 2009). The provision of personalized and context-aware assistance represents the other main aspect of personal health systems. Lifestyle oriented exercise programs foster physical activity, which is embedded in day-to-day life. Examples of such physical activities are walking, cycling, household chores, or playing with the kids and are often described as active lifestyle (Baumann, 2007). A major aspect of lifestyle oriented exercise programs is therefore everyday movement from a location A to another location B. In this context, cycling was identified as suitable physical activity for the novel approach since it has a functional role which does not completely rely on self-motivation and can contribute to a higher level of physical activity (Haines, McMichaels, Anderson and Houghton, 2000). Another reason for this decision is the fact that cycling on automatically adaptive cycle ergometers is often used for exercise therapy in phase II in rehabilitation centers. Therefore, a patient is already familiar with such a exercise device. With the new developments in electric power assisted cycles automated adaptation of assistance level similar to cycle ergometers is possible. In this context pedelecs are of great interest, since they are cycles which are equipped with an electric auxiliary motor that cannot be exclusively propelled by that motor, i.e. the motor assists only when the cyclist pedals. Latest models provide a mobile app to adjust the assistance level, i.e. a smart phone instead of the integrated control unit is attached to the handlebar and sends commands about the assistance level to the motor. In addition the smart phone is connected via mobile broadband. Connection on the one hand allows the collection of information about a user's context. Different data 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. Furthermore, the mobile internet connection of the smart phone allows for the transmission of the collected data to a server which is able to process and analyze it. With the analysis results appropriate feedback can be sent back to the cyclist. Examples of such feedback are automated adaptation of the assistance level of the motor or location-based services, i.e. information on surroundings, change options to public transfer, etc. (Chapko, Feodoroff, Werth and Loos, 2012). The description shows that the main conceptual aspects of personal health systems, recognition of context and feedback, are met with the described connected pedelec. Furthermore, due to the functional role of the pedelec as means of transport an easy integration in day-to-day life is possible. This especially applies even more due to the fact that a pedelec can be used both stationary as an indoors exercise device and mobile as a mean of transport outside. For both scenarios recognition of context and feedback are always given with the connected pedelec. In the following section a conceptual architecture of the novel approach for lifestyle-oriented cardiac rehabilitation and disease management is depicted in figure 1.

Conceptual architecture for a lifestyle-oriented approach in cardiac rehabilitation and disease management

As described above a major shortcoming of traditional cardiac rehabilitation and life-long disease management can be found on different levels. These are data management, interaction of the different care takers (e.g. medical rehabilitation professionals, therapist, general practitioner and relatives) and provision of health services. Data management and management of the network of care takers completely rely on the patient, who is the weakest link in the network of people working on the improvement of the patient's health. In terms of provision of services the decrease of medical services throughout the process was identified as a normal development. However, as the number of medical services decreases, services for disease management and behavioral changes should support patients to better deal with the disease. In this context, some educational services are provided in phase III. Educational service beyond phase III are not available as well as assistive services which should be ideally embedded in everyday life. Based on these three levels the conceptual architecture depicted in figure 1 is described in the following.

A central platform consisting of a **mobile side** and **server side** provides the basis to improve cardiac rehabilitation on the three levels described above. Since mobility is an important factor to embed and support rehabilitation process and services in daily life, the system is designed to consist of a mobile side which is represented by a smart phone. The smart phone is connected to the electric bicycle and collects context information from different sensors (**external sensor** such as body sensors and **internal sensors** such as integrated sensor in the smart phone or the electric motor). A modular designs ensure that as many sensors as necessary can be integrated, so that more parameters can be measured. The gathered data is pre-processed and a first set of analyses is performed in the mobile **rule engine** to – for instance, **automatically adapt the electric cycle motor** - or provide simple feedback in case of no signal or to reduce network traffic to the server. With that approach data analysis can be conducted in real-time and personalized feedback can be provided. The data is then sent to the server where it is processed more elaborately in the **analysis component** and personalized and context-aware recommendations are generated by the **recommender system**. The tailored feedback is then sent back to the smart phone, where it is presented to the patient via a **graphical user interface**. A **learning component** creates an implicit **user profile** based on observed actions of the patient, i.e. a user profile not actively sought from the patient, but derived from the interactions of the patient with the system. Since behavior might change over time, the learning component provides the necessary functionalities to adapt to a patient, without active patient involvement. The learning component enables an improved tailoring to the patient over time. An explicit **user profile** is provided by patients themselves (**primary user**) and **secondary user**s which are for instance medical professionals or relatives. Therefore, the system is also accessible via a PC for instance via a **web interface**. The goal is an improved data management for all involved parties and the inclusion of the patient In addition, data from hospital information systems is provided via the integration of **third party services**, i.e. an interface to the hospital information system.

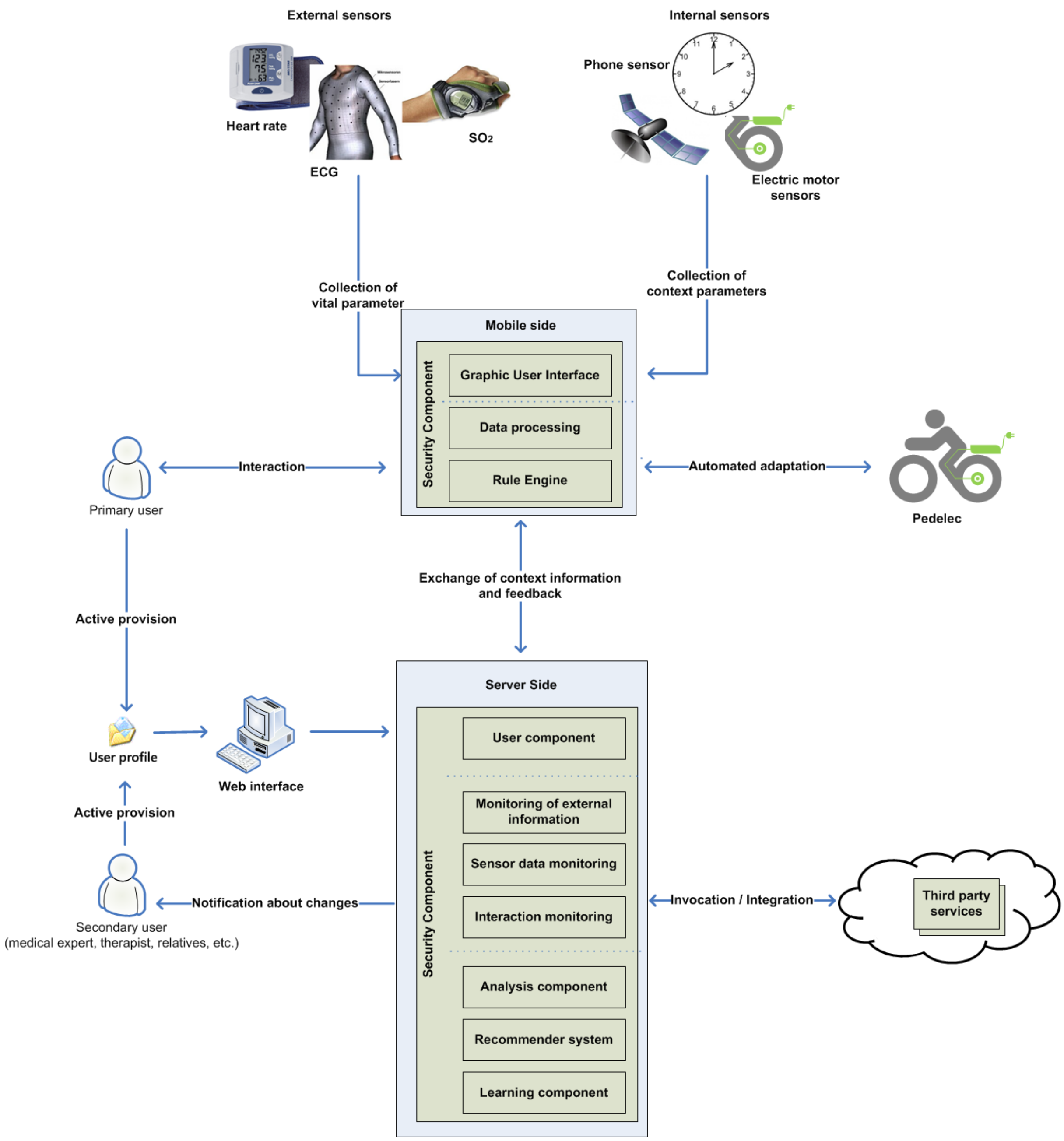

Figure 1. Conceptual architecture for lifestyle-oriented cardiac rehabilitation

The server side contains the main components for an improved management of network of care takers. The **user component** provides all functionalities of a virtual community. Here, patients can connect with other patients or relatives and talk about their favorite routes they recently rode on the pedelec, set up exercise meetings or exchange experiences about managing their disease. The idea is to provide an easy way for patients to connect with their peers and relatives. In addition, patients can grant access to their **user profile**s (direct and indirect) to medical professionals and relatives. Medical professionals can monitor the progress and provide feedback, e.g. adjust the training plan, recommend a medical exam, etc.. The

recommender system not only support patients but also medical professionals by providing automated feedback on the progress and proactively point out observed developments. Also coordination of phase III activities and required paperwork can be conducted via the **user management**. Overall, user management provides the support to better coordinate the activities of **primary and secondary users** and to assist mainly a patient, but also the involved parties.

In terms of health services the analysis of traditional cardiac rehabilitation showed, that disease management services are merely educational and not assistive. With the novel approach assistance during life-long disease management can be easily conducted. As described above a much more elaborated data management system is available in phase III and beyond phase III. Based on that and the incorporation of a pedelec, automatically adaptive training is now also available in phase III and beyond phase III. Furthermore, the integrated **recommender system** can assist a patient proactively with personalized and context-aware services. For instance during a training unit, location-based information about nice viewpoints or rest opportunities (restaurants, etc.) can be provided to the patient and increase motivation. Also **third party services** such as public transport integration to point out the next bus stop in the vicinity and a bus schedule for the trip home can be provided in addition to the recommendation to stop the exercise due to exertion. At home services which support behavioral change can be provided on the PC or the smart phone. For instance, information on stretching techniques, recipes for health meals, latest news on management of cardiac diseases, etc. can be tailored to individual needs and current situations and provided aware of a patient's context.

Since sensitive data is collected, analyzed and exchanged, every component of the mobile side as well as the server side is embedded in a **security component**. Here, secure data exchange, access rights management, etc. are provided. Patients are owners of their data and actively have to grant other users access to their data. Furthermore, they have to actively agree to the usage of their data for analysis, feedback, etc.. In addition, the security component monitors and enforces compliance with national and international data protection acts.

In phase III and beyond phase III patients are usually on their own and have to find out for themselves, how to manage rehabilitation and their disease. With the described approach patients are provided personalized assistance and better improved integration with care takers. With the usage of a pedelec and a connected smart phone integration with daily activities is easier for patients and thus, adherence.

RELATED WORK

To the authors' knowledge there are no similar systems available for the ICT-based management of phase II, phase III and life-long disease management for cardiac rehabilitation. Approaches tackling sub-issues are described in the following. Overall, mainly decision support systems are provided by the described approaches. Feedback is mostly limited to the provision of current health status and motivational information. No assistance systems providing personalized and context aware feedback and/or automated adaptations are provided.

In the European project SAPHIRE (Nee, Hein, Gorath, Hülsmann, Laleci, Yuksel, Olduz, Tasyurt, Orhan, Dogac, Fruntelata, Ghiorge and Ludwig, 2008), a tele-monitoring system for exercise therapy at home was developed. The goal is to provide a similar setting as in the rehabilitation center to foster maintenance of exercise therapy at home. A stationary cycle ergometer sends monitored vital parameter via WLAN to a hospital server. Feedback of the SAPHIRE system is automated adaption of resistance of the ergometer and initiation of an emergency call, if necessary. Decision support is based on clinical practice guidelines and patient history. The European project HeartCycle (Reiter, 2011) aims at the provision of continuous feedback to cardiac patients about their status of health and their progress towards achieving health status milestones. In addition, motivational tips and information for a healthy lifestyle and diet are provided. Monitoring is conducted via unobtrusive bio-sensors built in a patient's clothing or bed sheets and home appliances (e.g. weighing scale or blood pressure monitors). The collected data is provided to medical professionals who then respond by adapting care plans individually. Similar to SAPHIRE, emergencies scenarios are handled by the system as well. The European project MyHeart (Couceiro, Carvalho, Henriques, Antunes, Harris and Habetha, 2008) aims at developing an intelligent system for prevention and early diagnosis of cardiovascular diseases In terms of physical activity it automatically determines the specific activity and provides feedback on the present status as well as on the achieved improvement of the physical status. Potential motivational issues are tackled actively by feedback on status, community building and virtual competition. In terms of services for behavioral change a strong focus is put on bio-feedback. The target group of the knowledge management system developed in the European project NOESIS (Exarchos, Tsipouras, Nanou, Bazios, Antoniou and Fotiadis, 2005) are medical professionals in the area of cardiology. An integrated decision support system supports clinical decisions in emergency situations and during daily work.

SUMMARY AND OUTLOOK

The paper describes a conceptual approach for an improved cardiac rehabilitation with a focus on assisting patients with their disease management in daily life. At first, shortcomings on the levels of data management, interaction of the different care takers and provision of health services were identified in traditional cardiac rehabilitation. Then, a conceptual architecture of an ICT-based personal health system is described which improves data management in terms of increased amount of context data in phase III and beyond phase III and the combination of machine-based evaluation (partly in real-time) and expert analysis. Not only is more data available in phase III and beyond phase III but patients are also able to grant laypersons and medical professionals access to their data. Furthermore, the network of care takers is enhanced by providing the ability to connect with peers beyond phase III. In terms of automatically adapted exercise the novel approach makes it on the one hand available in phase III, on the other a stationary and a mobile execution is possible with the described connected pedelec. Automated adaptations to patients' needs are furthermore available for provision of health services. Therefore, a recommender system was integrated in the conceptual architecture which provides personalized and context-aware services on patients' request and proactively. It is also able to learn from the interactions of patients' and extend user profiles with the detected patient-specific behavior.

In a next step inclusion of step I in the conceptual approach will be examined. In this context, inclusion with the hospital information system needs to be further investigated. In terms of acceptance by primary and secondary users, further investigations need to be conducted about data security.

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REFERENCES

1. Baumann, A. (2007) Physical activity and exercise programs, In *Physical activity and health*, C. Bouchard, S. N. Blair, and W. Haskel (eds.), Champaign: Human Kinetics, 319–334.
2. Binder, R. K., Wonisch, M., Corra, U., Cohen-Solal, A., Vanhees, L., Saner, H. and Schmid, J.-P. (2008) Methodological approach to the first and second lactate threshold in incremental cardiopulmonary exercise testing, *European journal of cardiovascular prevention and rehabilitation : official journal of the European Society of Cardiology, Working Groups on Epidemiology & Prevention and Cardiac Rehabilitation and Exercise Physiology*, 15, 6, 726–34.
3. Bock, B. C., Carmona-Barros, R. E., Esler, J. L. and Tilkemeier, P. L. (2003) Program participation and physical activity maintenance after cardiac rehabilitation., *Behavior modification*, 27, 1, 37–53.
4. Chapko, A., Feodoroff, B., Werth, D. and Loos, P. (2012) A personalized and context-aware mobile assistance system for cardiovascular prevention and rehabilitation, In *Lebensqualität im Wandel von Demografie und Technik*vde-verlag, 7.
5. Codagnone, C. (2009) *2020, eHealth and personalised health care in arrhythmias - Personal Health Systems: a roadmap to 2020*.
6. Couceiro, R., Carvalho, P., Henriques, J., Antunes, M., Harris, M. and Habetha, J. (2008) Detection of Atrial Fibrillation using model-based ECG analysis, In *2008 19th International Conference on Pattern Recognition*IEEE, 1–5.
7. Exarchos, T. P., Tsipouras, M. G., Nanou, D., Bazios, C., Antoniou, Y. and Fotiadis, D. I. (2005) A platform for wide scale integration and visual representation of medical intelligence in cardiology: the decision support framework, In *Computers in Cardiology, 2005*, IEEE, 167–170.
8. Goble, A. J. and Worcester, M. C. (1999) *Best Practice Guidelines for Cardiac Rehabilitation and Secondary Prevention*Carlton, 238.
9. Haines, A., McMichaels, T., Anderson, R. and Houghton, J. (2000) Fossil fuels, transport, and public health, *British Medical Journal*, 11, 1168–1169.
10. Hevner, A. R., March, S. T., Park, J. and Ram, S. (2004). Design Science in Information Systems Research. MIS Quarterly, 28, 75-105.

11. Keck, M. (2000) Optimization of the transition from phase II to III of cardiac rehabilitation, *Die Rehabilitation*, 39, 2, 101–5.

12. Kligfield, P., and Lauer, M. S. (2006) Beyond the ST Segment Beyond the ST Segment, *Contemporary Reviews in Cardiovascular Medicine Circulation*, 114, 2070–2082.

13. Kouidi, E., Farmakiotis, A., Kouidis, N. and Deligiannis, A. (2006) Transtelephonic electrocardiographic monitoring of an outpatient cardiac rehabilitation programme, *Clinical rehabilitation*, 20, 12, 1100–4.

14. Lewis, M. J. and Short, A. L. (2010) Exercise and cardiac regulation: what can electrocardiographic time series tell us?, *Scandinavian journal of medicine & science in sports*, 20, 6, 794–804.

15. Marios, T., Dalton, S. and Smart, N. A. (2012) The effect of tele-monitoring on exercise training adherence , functional capacity , quality of life and glycemic control in patients with type II diabetes, November 2011, 51–56.

16. Nee, O., Hein, A., Gorath, T., Hülsmann, N., Laleci, G. B., Yuksel, M., Olduz, M., Tasyurt, I., Orhan, U., Dogac, A., Fruntelata, A., Ghiorghe, S. and Ludwig, R. (2008) SAPHIRE: intelligent healthcare monitoring based on semantic interoperability platform: pilot applications, *IET Communications*, 2, 2, 192.

17. Piotrowicz, E., Baranowski, R., Bilinska, M., Stepnowska, M., Piotrowska, M., Wójcik, A., Korewicki, J., Chojnowska, L., Malek, L. A., Klopotowski, M., Piotrowski, W. and Piotrowicz, R. (2010) A new model of home-based telemonitored cardiac rehabilitation in patients with heart failure: effectiveness, quality of life, and adherence, *European journal of heart failure*, 12, 2, 164–171.

18. Piotrowicz, E. and Piotrowicz, R. (2011) Cardiac Rehabilitation Telemonitoring in Heart Failure Rehabilitation, *European Cardiology*, 66–69.

19. Reiter, H. (2011) *HeartCycle Deliverable 18.B*, 1–32.

20. Smart, N., Haluska, B., Jeffriess, L. and Marwick, T. H. (2005) Predictors of a sustained response to exercise training in patients with chronic heart failure: a telemonitoring study, *American heart journal*, 150, 6, 1240–7.

21. Tenenbaum, A., Freimark, D., Ahron, E., Koren-Morag, N., Schwamenthal, E., Fisman, E. Z., Shechter, M., Tanne, D., Kachlon, D., Motro, M. and Adler, Y. (2006) Long-term versus intermediate-term supervised exercise training in advanced heart failure: effects on exercise tolerance and mortality, *International journal of cardiology*, 113, 3, 364–370.