User Centered Design of an Interactive Mobile Assistance and Supervision System for Rehabilitation Purposes

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Abstract. This paper describes the user centered development of a mobile assistance and supervision system for cardiac disease patients. Smartphones are used to collect data from wireless sensors like ECG, blood pressure or oxygen saturation sensors while a patient is exercising outdoors. All data from the wireless sensors as well as GPS information is sent to a supervision center where doctors and sport therapists analyze the data in a collaborative and interactive setting. We here present the User Centered Design process, the technical realization as well as the interaction modalities of our system.

Keywords: Mobile rehabilitation, cardiac diseases, telemedicine, mobile assistance, interactive visualization, supervision, user centered design.

1 Introduction

Cardiorespiratory fitness is a health protective factor. "Fit people", persons with a high fitness level, have a longer life expectancy [1] since physical activity reduces the risk of a cardiac event by the positive adaptation of the musculoskeletal and cardiovascular system [2]. Therefore, in Germany health initiatives have been established to increase the motivation for physical activity. Such initiatives are not set up for specific diseases but address the average population.

Cardiovascular diseases (CVD) remain the number-one cause of deaths worldwide, with more than 80% of deaths from CVD in low- and middle-income countries [3]. The reduction of mortality is associated with the activity level. People with CVD need an adapted and monitored training to avoid over exertions and prevent further cardiac events. Cardiac rehabilitation is established after a cardiac event in order to minimize the cardiovascular risk factors in the long term. However, existing studies indicate that the success of this kind of rehabilitation only persist for about one year [4] since

B. Godara and K.S. Nikita (Eds.): MobiHealth 2012, LNICST 61, pp. 41–50, 2013.

follow-up offers don't exist and patients tend to abort continuous exercises and a healthy lifestyle.

In Germany outpatient heart groups are the only offer of cardiology secondary prevention. However, these groups are not nationwide represented and temporally inflexible, so that only about 13-40% of CVD patients participate [5]. Therefore, health initiatives that are geared specifically to elderly and persons with CVD are extremely necessary. For that reason within the ITEA2 research project "OSAmI - Open Source Ambient Intelligence Commons", funded by the Federal Ministry of Education and Research in Germany, an indoor bicycle ergometer with an integrated telemonitoring system was developed. In collaboration with computer-, information- and sports scientists as well as medical technicians an intelligent bicycle ergometer for patients with CVD was built. The ergometer bike can be controlled by a patient via a 15" touch screen that is mounted to the handlebar. The vital data of a patient is measured using a 3-lead-ECG, an oxygen saturation sensor and a blood pressure sensor. All sensors use Bluetooth for sending the vital data wirelessly to a nearby receiver station. This station is connected to the Internet and sends all vital data and all bike data in real-time to a medical center, where supervisors observe the data. A supervisor can adapt the training and remotely change the bike settings. Further on, the system has an integrated alarm system to prevent over- and under-loads [6].

Since heart patients need different types of training regarding different histories of CVD and because of the different cardiorespiratory level, the OSAmI system offers three different exercise types: heart rate controlled training, constant load training and interval training. To gather personal feelings about the current wellbeing of the patient, they need to answer questionnaires before and after every training in order to get information about medication intake, the deterioration of the disease, the perceived difficulty of the training etc. The OSAmI system has a huge potential to motivate and support elderly people and patients with CVD to physical activity [7]. A training can be absolved flexible in time and under safe conditions, because the vital data is live monitored and the supervisor is able to adapt the load and duration of the training immediately. The attractiveness of this form of training was rated very high in a first user study [8].

However, an indoor ergometer training can be very monotonous. Therefore, we developed an outdoor scenario that is introduced in this paper. Patients participating in the OSAmI program can take their wearable equipment outside. A mobile gateway like a smartphone is needed to collect the data from the wireless sensors and send it to the medical center for supervision. Further on, GPS information is collected and also transmitted. The vital data can be monitored while patients are hiking or cycling outdoors producing a save feeling for them. Further on, the mobile gateway is able to locate the trained person. If an acute cardiac event happens, the emergency doctor can locate the patient rapidly.

The structure of this paper is as follows: We will first address some related work in the area of mobile supervision and observation systems as well as our work on User Centered Design (UCD) within the OSAmI project. Next we will describe the technical realization of the mobile scenario. We will further on introduce an interactive setup that allows a team of medical experts to supervise the mobile data on a tabletop device. The paper ends with a conclusion and some ideas for future work.

2 Related and Previous Work

Since smartphones are wide spread these days and millions of mobile Apps have been programmed and published, there are also many of them that address sportsmen or people who need extra care. Many so-called sport tracker applications are available, e.g. Endomondo[1] or Sports Tracker[2]. These Apps are available for various kinds of smartphones and besides GPS data they are also able to measure the heart rate of the user via chest straps. As long as a mobile data connection is available the data is transmitted to a portal where the community can see the current location and heart rate of a user. However, supervising cardiac disease patients is much more critical since a huge amount of data like ECG has to be transmitted in real-time. Therefore, until now these applications are only suitable for sportsmen, not for cardiac disease patients to control exercise.

In the area of medical assistance many mobile application scenarios have been developed and realized. Also applications that analyze ECG data have been created, e.g. for ECG monitoring at night-time [9]. Other systems collect data that is not that dynamic and critical, like the weight of a patient, her nutrition during a day or general activity analysis [10] using acceleration or GPS sensors. The home-based cardiac rehabilitation care model "TuneWalk" [11] is a measurement system and software tool for a mobile phone platform. This mobile application gives guidance to the patients during home exercises using heart rate and physical activity analysis and also stores long-term information about their progress during the weeks of the rehabilitation program. The measured data is sent to a server for remote exercise performance analysis and consultation by the patient's personal mentor. However, most approaches are quite simple and do not consider real-time transmission of vital data or live supervision. Further on, they do not address the special use case of rehabilitation and sport exercises.

Cardiac disease patients require individual training plans and often also live supervision and adaptation of these plans. For every critical patient medical supervisors need to know the vital data like ECG, blood pressure and oxygen saturation in real-time. The OSAmI system offers all the technical components that are needed to turn this scenario into reality.

However, in order to create a medical product also the usability is an important factor. User Centered Design (UCD) is an established methodology in the software-industry that focuses on the users of a future system and aims to create solutions that fits the users needs, their requirements and supports their tasks and goals. The usability of products gains in importance not only for the users of a system but also for manufacturing organizations. According to Jokela [12], the advantages for users are far-reaching and include increased productivity, improved quality of work, and

[1] http://www.endomondo.com/
[2] http://www.sports-tracker.com/

increased user satisfaction. Manufacturers also profit significantly through a reduction of support and training costs [12]. In order to create usable solutions it is necessary to involve potential users in early stages and during the process of development. UCD adds to this by providing methods applicable at different stages in the process of development.

To sum up, technical approaches exist that address sportsmen or elderly people who need special care. However, to the knowledge of the authors no system exists that offers the mobile collection of vital data like ECG, transmits this data in real-time to a supervision center and offers supervisors the possibility to observe multiple patients at the same time in a collaborative setting. Therefore, we will describe the technical realization within a UCD process that included patients, doctors, sports therapists and sport scientists in the next sections.

3 The Mobile Client

This section describes the technical realization of the mobile rehabilitation client that runs on a smartphone. It's main task is to manage the communication to the supervision center and transmit the sensor data. Further on it must provide an easy to use user interface and assist a patient especially in critical situations.

On technical level the system is message-based. All clients as well as the server application share a common XML-based message format and connect transparently using the XMPP protocol. With XMPP an arbitrary number of devices can be used platform-independently. The protocol supports presence detection and various communication schemes like publish-subscribe, notifications, etc. The architecture distinguishes between three categories: mobile trainee clients, mobile coach clients and stationary clients. The mobile trainee client (realized with Android™) connects to the vital data sensors using Bluetooth but also other communication technologies like ANT+ have been implemented. The monitored data is processed using the C-LAB context store[3] component, which is an open-source framework for designing arbitrary context processing solutions. Whenever communication is available monitored data is send to the central server. On this server the coach clients are registered as recipients of the data. The combined data is then transferred to these clients. The architecture allows simultaneous use of a mobile coaching client and the stationary solution (see next chapter).

On the client side the information from the sensors and the user portal is processed. The trainee can see her training schedule and her position on the map including the tracks (see figure 2). In one of our first interview sessions with patients we found out that patients want to be able to see their own vital data on a display [8] (which isn't the case during an on-site ergometer training in the clinic). Therefore, the vital data is displayed and if predefined limits are violated automated warnings are given. The warnings are presented using multimodal feedback via audio, vibration feedback and

[3] http://www.c-lab.de/en/publications/services_downloads/c_lab_open_source/contextstore/

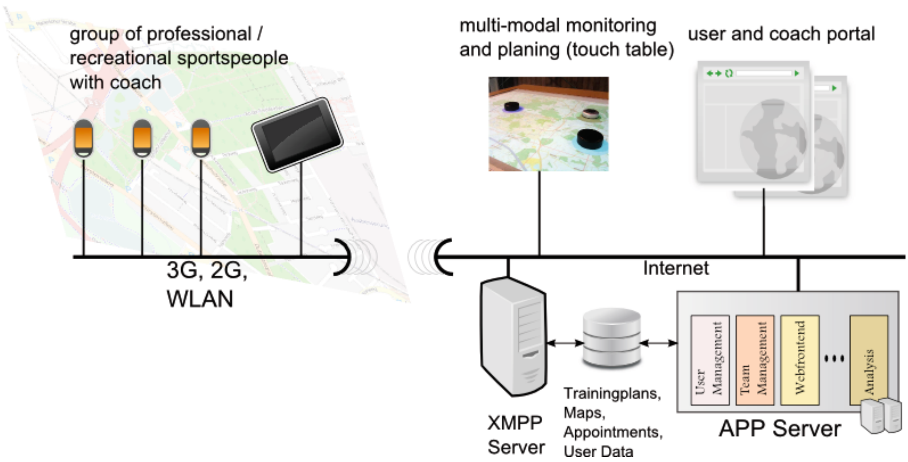

Fig. 1. OSAmI architecture

visually on the smartphone screen. This ensures that she is informed about important information even though she's currently exercising without having the device in front of her (e.g. wearing it in a pocket). An online supervisor receives the same data and alerts. Additionally she can directly modify the training parameters, or contact the trainee. In a medical scenario the recorded data can be discussed with the trainees and the training plans can be adapted. The screenshots in figure 2 demonstrate the mobile trainee application in action.

On the server (see figure 1) the training data is managed and the training plans are provided for the trainee. Training plans can contain different activities of various sport types with specific constraints on the vital data. They are based on one of the OSAmI-Trainings presented in the beginning (heart rate controlled, constant load or interval). Connection loss is handled transparently. If the connection is restored all buffered data is transmitted automatically so there is no "gap" in the final training report.

The entire system has been realized by COTS (Samsung Galaxy Tab, Samsung Galaxy I9000) and standard open-source server implementations. The results from our earlier studies for designing the user interfaces and icons [8] were used during the development. In the next section we will described how the vital and GPS data of the mobile clients is supervised by medical experts in a collaborative setting.

4 Collaborative Supervision

During one of our on-site studies [13] we have observed that the supervision of cardiac disease patients during rehabilitation exercises can ideally be performed in teams. In the cardiology clinic *Schüchtermann Schiller'sche Kliniken* in Bad Rothenfelde, Germany, we observed that often teams of two or three sport therapists or doctors supervise a group of about 16 patients exercising on ergometer bicycles.

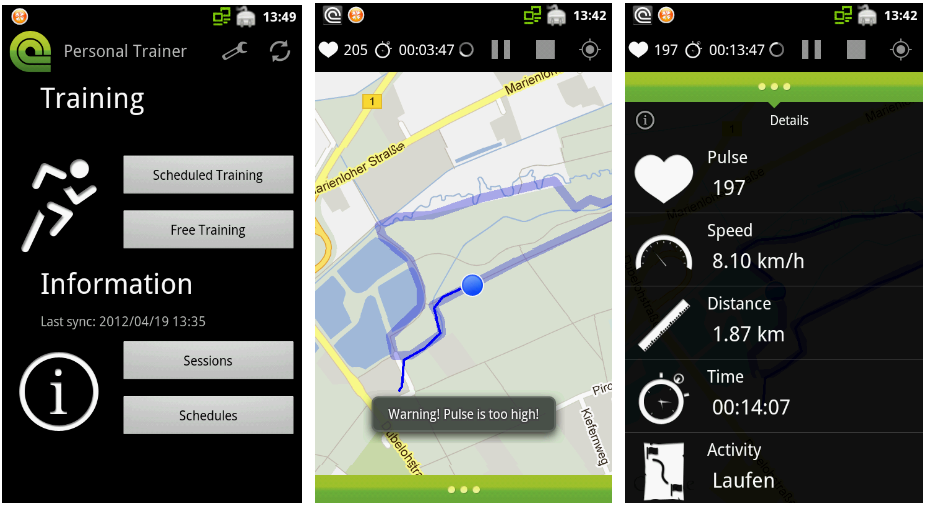

Fig. 2. Screenshot of the mobile client

Since outdoor exercises are much more dynamic they require a more concentrated observation. Therefore, we think that a supervision team of four or five sport therapists, doctors or other medical experts might be suitable to observe a group of up to 20 patients. This is because there might be several patients at the same time that need detailed supervision, the risk of missing a critical situation is lower but also because the supervision can be best performed within a collaborative decision process, so discussions between supervisors are very important. The challenge is to create a working environment that supports group work, enables the visualization of huge amount of data and supports collaborative decision processes at the same time. Further on, everyone from the group must be able to interact with the system at any time and the usability of the system has to taken into account because critical decisions have to be made within seconds frequently.

Therefore, we extracted the requirements for a collaborative supervision system within a UCD process that included interviews and observations. During a first visit we observed an on-site training in the clinic in order to get familiar with the current training setup and procedure. We recognized that supervising sport therapists not that much focus on the two large-scale monitors where all the vital data of the patients is presented but often walk around in order to visually observe the patients and talk to them. During a second where visit we held interviews with four sport therapists we got the feedback that the overall well-being of a patient can best be analyzed by observing their behavior, movements, skin color or sweating condition. Since such kind of observation is not possible in remote situations it is very important that:

- More than one supervisor is present in order to reduce the risk for overseeing a critical event. We therefore designed the supervision application in such a way that about five supervisors can use it coactively.
- All information about the patients is available to every supervisor. Since displaying all information at the same time would end up in a confusing user

interface only the most important things (alerts and GPS positions) are presented while all other data is callable on demand. The presented information must be visible from different position and adjustable by every supervisor easily.

- Algorithms for the automatic detection of events like over- or under exceeding a limit previously assigned to a vital data value are used and alarms occur.
- Supervisors can send feedback like audio or text messages to the patients.
- Routines for handling malfunctions in the data transmissions exist (e.g. informing the patients about connection errors and giving hints on how to proceed or pause the training).

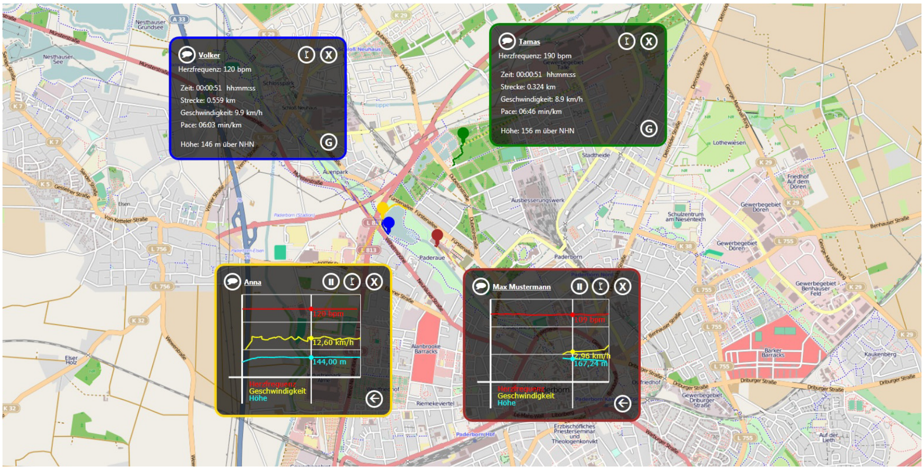

Fig. 3. Screenshot of the tabletop application showing details of four simultaneously exercising patients

Using this requirements we created a prototype application on our multitouch table useTable[4] (see figures 3 and 4). The useTable offers a 72” horizontal multitouch screen with full HD image projection. Past research has proven interactive tables to be especially beneficial for collaborative decision support systems [14,15]. The size of the useTable is perfect for groups of five or six people distributed on all sides of the table. Besides multitouch the useTable is also able to detect physical objects (*tangibles*) that are placed on the screen. We used these tangibles for map manipulation. After a tangible is placed on the table zooming can be performed by rotating the tangible and moving the map is performed by moving the tangible. Since only one map-tangible exists everyone in the group can see and understand what is happening and which person is currently interacting with the map. This realization perfectly addresses the interaction awareness [16] of the group. Further on, multitouch gestures for map interaction would end up in chaos because often multiple persons are touching the table at the same time. Figure 3 shows a screenshot of the application. It can be seen that four patients are exercising at

[4] http://www.usetable.de

this time. The windows with detailed information about vital data can be popped up or minimized by touching the patient's icon on the map. Users can switch between textual and graphical representation by clicking a button in the window. If an alarm occurs (e.g. the vital data has exceeded a predefined limit or a patient's smartphone lost it's connection), the information window pops up automatically. All windows on the screen can be moved, rotated and scaled using multitouch gestures allowing everyone on every side of the useTable to see the data and interact with it. In order to change the limits for heart rates etc. a user has to identify herself by placing a so-called chief-tangible on the table. Doing so creates a popup window that allows for such kind of manipulations (see figure 4, right). This addresses the required rights and role-management since not every supervisor is allowed to change these values for every patient.

Fig. 4. Picture of the useTable (top left) and a tangible object allowing an authenticated changing of heart rate limits (right: select patient, bottom left: change limits)

In the third step of the UCD process we invited qualified clinic staff (doctors, sport therapists and sport scientists) to review this prototype and got positive but also critical feedback. In general the system was evaluated as highly interactive and very useful. However, there is still some work to do to address the specific use case of collaborative supervision of heart disease patients. Therefore, the next version of the system will include a third party ECG renderer. Further on the authentication through the tangible objects has to be improved. At the moment the recognition is done by a simple black and white pattern that can be easily reproduced. We are currently working on an RFID based authentication [17]. Last, we are planning to implement algorithms that address the loss of connection of a smartphone during exercises. For a limited period of time the system could forecast this situations and also forecast future positions and vital data based on available routes and altitude profiles.

5 Conclusion

In this paper we introduced the mobile OSAmI system that we developed within a User Centered Design process. Cardiac disease patients can use their smartphone for collecting vital data like ECG, blood pressure or oxygen saturation from wireless sensors. This data, as well as the GPS position, is sent to an observation center where a team of medical experts can supervise the training of multiple trainees in a collaborative setting including an interactive tabletop device.

Even though the User Centered Design process is still ongoing and the system still a prototype we think that this approach has a huge potential. In the next iteration of the process step we plan to solve the problem of loosing network connectivity by predicting positions and vital data developments. After doing some refinements on the visualization and interaction the next review by experts from the clinic is planned. Further on, the developed technology is also suitable for other use case scenarios.

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