Preliminary Version

CordiAAL: Enhanced Motivation for Cardiological Ergometer Training through Virtual Groups in Virtual Worlds

Israfil Akman[1], Rafael Bielen[1], Henning Brümmer[1], Egor Kudrjaschow[1], Stefan Tschentscher[1], Oliver Dohndorf[1], Heiko Krumm[1], Jan-Dirk Hoffmann[2], Anke Workowski[2] and Detlev Willemsen[2]

[1]*Lehrstuhl Informatik IV, TU Dortmund University, Martin-Schmeißer-Weg 18, 44221 Dortmund, Germany*

[2]*Schüchtermann-Schiller'sche Kliniken, 49214 Bad Rothenfelde, Germany*

{forename.surname}@tu-dortmund.de, {First forname character}surname@schuechtermann-klinik.de

Keywords: Ambient Assisted Living, Bicycle Ergometer, Cardiac Disease, Preventive Programme, Secondary Cardiac Prevention, Immersive Virtual Reality

Abstract: The project CordiAAL purposes the goal of developing a training system for patients with cardiovascular diseases. The first aim is to reduce the anxiety of overexertion by using a continuous monitoring of vital parameters and the second is to increase the patients' motivation according to a moderate physical activity by the virtual environment of the system. The training can be done alone or in common with several patients in a virtual group, regardless of the patients' location. When grouped together, the performance of the individual patient is aligned, so that patients with different fitness levels are able to work together. The evaluations revealed that the increase in motivation could be achieved by training in the virtual environment in virtual groups.

1 INTRODUCTION

Cardiovascular diseases are the leading causes of deaths in industrialized countries. In Germany there are 40.2% of all deaths based on cardiovascular diseases (CVD) (Statistisches Bundesamt, 2011). Mainly elderly people, 65 years and more, die because of these diseases. In 2011 the mortality rate of over 65 year old people was 92% (Statistisches Bundesamt, 2011). Around 15% of medical expenses, with 37 billion euros, were spent for these morbidities for the care, treatment, prevention and rehabilitation in Germany 2008 (Statistisches Bundesamt, 2008). These facts increase the meaning of primary and secondary prevention of people with CVD. Up to 90% of the cardiovascular morbidities are caused by the cardiovascular risk factors: dyslipidemia, hypertension, diabetes mellitus, obesity, distress and physical inactivity (Yusuf et al., 2004). Large epidemiological studies and meta-analyzes of randomized, controlled studies (evidence-based medicine, level IA) have shown that regular physical endurance activity is associated with a reduction of cardiovascular morbidity and mortality (Nocon et al., 2008). Therefore physical inactivity is considered the most important modifiable risk factor (Bjarnason.Wehrens et al., 2009). According to results of the National Health Survey only 41% of German adults (45 up to 65 years old) are more than 2 hours physically active per week, about 38% in this age group do not exercise and around 48% of German people older than 65 years do not exercise (in Deutschland aktuell Telefonischer Gesundheitssurvey (GEDA) des Robert-Koch-Instituts, 2010). The fitness level of a person is correlated with the exercise outcome. The life expectancy of "Fit People", people with a high performance, is higher than for people, who do not perform exercises regularly (Sattelmair et al., 2011). The risk of a cardiac event is reduced through regular physical activity by positive physiological adaptations (Lee et al., 2003) and the major modifiable risk factor is physical inactivity (Balady et al., 2007).

Because of this background cardiac patients train their physical activity during cardiac rehabilitation. It is largely documented that the traditional rehabilitation after discharge from hospital is efficient and acknowledged generally. Several studies confirm that the cardiac rehabilitation improves the functional capacity and psychosocial resources. But this success is not a long term effect (Kotseva et al., 2009), after one year, the output level is usually reached again. This lifts the obligation and responsibility of every individual to make secondary preventive care. In Germany, the secondary prevention of heart patients provides outpatient heart groups only. However, only 13-40% of all CVD patients do participate (Bjarnason-Wehrens et al., 2006). Reasons for this lack are that these groups are temporally inflexible and not nationwide available. In addition, there is a high drop-out rate of new members (Bjarnason-Wehrens et al., 2006). IT-based systems providing Ambient Assisted Living functions can be a solution. Therefore the chair IV of the Technical University of Dortmund and the Schüchtermann-Schiller'sche Kliniken in Bad Rothenfelde developed a virtual biking application as a part of a two-semester project, which should motivate patients to do exercises regularly. The CordiAAL project is an attempt to break the monotony of regular ergometer training sessions with virtual adventure components and to sustain the motivation and adherence of CVD patients. Healthcare professionals and computer science students developed a software for a bicycle ergometer in combination with a PC and wireless sensors (ECG, respiration rate, body temperature, oxygen saturation, blood pressure). The system is integrated into an internet based community, called RehaWeb, a special website for heart patients, with a combination of social networking features, editorial contents as well as mobile support and monitoring (Dohndorf et al., 2012). The user can go by bike through a virtual environment with a movable control and a virtual reality head-mounted display (HMD), that the session is as real as possible. The bike consists of a heart-rate controlled load system. The cardiologist can define individual corridors for each vital parameter and can set the optimal load for each user to prevent overexertion and underexertion. The training can be fulfilled online in a group of up to six users with different performances or alone in a single modus. Users can virtually train together without actually being together. Thereby heart patients will be motivated through the advanced sensor-based gaming environments to do exercise. With the defined limits of the vital data, the users can loose their anxiety of exercise and get more body awareness. For the documentation of the training and vital data a report of each session is generated. The CordiAAL system can support a sustained prevention and rehabilitation of people with CVD. The CordiAAL project is based on the results of "OSAMI - Open Source Ambient Intelligence Common", which was funded by the Federal Ministry of Education and Research in Germany (ITEA2) (Busch et al., 2009). This paper will introduce with related works, discuss the requirements and possible solutions to the system afterwards. The following section will describe the architecture of the system in detail. Finally, first evaluation results of the system will be presented.

2 RELATED WORK

IT-based systems, that motivate persons to do sports, can be categorized according to their nature as immersive and non-immersive systems, and regarding to the kind of environment where they are used. Some systems can be used at home, but others are made to be used in physical therapy.

One non-immersive system usable in every environment is the Geosocial Network (Boulos and Yang, 2013). This system requires a GPS and an internet-capable mobile phone. The application defines a target in the local area, where the user should travel to. At an easy level the target is clearly defined by GPS coordinates, but at a more difficult level the coordinates are hidden by small puzzles. When the user reaches the target, it is recorded in his profile and more challenges are unlocked. The profile of each user is also available in a web portal and is visible for other players. The training aspect of the Geosocial Network is based on the hiking of the users, whereas the achievement of objectives and the comparison with other players serve an enhanced motivation. Other examples of such systems are CodeRunner [1] or Dokobots [2].

The Wiihab system (Anderson et al., 2010) is immersive and made for physical therapy. It is designed for patients who have restricted moving abilities. This system requires a Personal Computer, a Wii Balance Board and a Wii Mote. The Wii Mote is a video game controller with a built-in motion sensor, the Wii Balance Board measures the weight and the balance of the patient. The Wiihab system has five built-in games. Every game trains a different aspect, like the balance of the body or the accuracy of the hand's movements. During a game session the training is automatically adapted to the patient's health status. After every session, the patient gets feedback about his training success. So, the Wiihab system increases motivation for rehabilitation training by playing games and the comparison with other players.

Furthermore, the Kinect system realizes a sensor-based gaming environment. Similar to the Wii, the

[1] http://www.coderunnergame.com/

[2] http://www.dokobots.com/

Kinect system motivates the users playfully to perform physical activities. This system is immersive and can be used in every environment. The Kinect is basically a camera which detects movements of the body. The user itself is the input device for a video game. That is unique and increases the immersive factor and hence the motivation. Examples of immersive and physical activity promoting video games are Your Shape [3] or UFC Personal Trainer [4]. These games have certain exercises, training different parts of the body and recording vital data during the training.

A very prominent example of an immersive system, only usable in hospital-like environments, is the game Re-Mission (Lampert et al., 2009). It is directed to children, who have cancer and aims at influencing the behavior and attitude of young patients positively to their disease. The game was created by Games for Health [5]. This organization has the objective to motivate patients' physical activities and hence prevent illness and disease with the help of video games. In this game the patient fights against the disease cancer, in particular against tumors and similar signs of cancer using various weapons.

3 REQUIREMENTS AND SOLUTION APPROACHES

In order to serve its purpose as an aid in the prophylactic and rehabilitation phase the envisaged project CordiAAL has to meet following social, technical and medical requirements:

Social Requirements

Easy usage of the application: Because the primary target user group consists of elderly patients which usually have little experience in dealing with modern media, the user-friendliness is of great significance. We take up this challenge by sticking to the five rules as described in (Caprani et al., 2012, p. 101). In respect of these rules, we firstly ensure a fast running system and secondly realize a very intuitive operation of the application, where, for example choices are limited in order not to confuse the user. Thirdly, the guidance through the application is very clear so that no ambiguities are given. Not least of all, the usage is evaluated intensively. An easy usage of the modified RehaWeb website is guaranteed, since it was evaluated for the original version (Dohndorf et al., 2012), and the extensions are maintaining the original RehaWeb principles and styles.

Building trustfulness: In the sensitive area of medical applications, the mediation of trust is a necessary prerequisite with respect to a high user acceptance. For that purpose, the users are informed about the relevant issues of data security, safety and data privacy. In the medical field the analysis of training sessions by medical professionals increases trust.

Increasing motivation to secure long-term use: Patients use to neglect their training in case of a motivation lack (Shahsavari et al., 2012). We focus on that with the main feature of CordiAAL, the group training mode, which keeps the motivation on a high level. Boredom is prevented through a common training with like-minded patients. Not least of all, the HMD and the voice chat are conducive to this. Moreover monotony does not arise due to the existence of several maps.

Reduction of fears: As it is generally known, patients with a cardiac disease commonly have to cope with fears (Eifert et al., 2000). Thus, the software CordiAAL pursues the goal of reducing these fears in several ways. Technically, thresholds for the heart rate, defined by medical professionals with respect to the health level of the patients, are used in each training session. Furthermore the training load during a training session is adapted instantly according to the current heart rate so that the risk of a further cardiac event during the training is minimized.
Socially, the user gets in contact with like-minded patients that suffer from a similar health issue, which helps to distract the user's fears. Furthermore, the training is not felt to be a training, instead it is felt to be a game.

Technical Requirements

Achievement of data security and privacy: We extend the RehaWeb project which already ensures these requirements. Our extension contains the web interface for the cardiologist where he can define and adjust vital thresholds for a patient and a detailed web statistic for each training. The statistics can only be accessed by authorized persons.

Recording of vital and load parameters: The vital

[3] http://www.ubi.com/DE/Games/Info.aspx?pId=10769

[4] http://www.golem.de/1104/82633.html

[5] http://gamesforhealth.org/

data have to be delivered from the body sensors to the client software. These data are the basis for the dynamic ergometer load control system. The vital data used in CordiAAL comprise the ECG, the respiration rate, the body temperature, the SpO2 level and the blood pressure.

Controlling functions and dynamic group control: The load and the RPM of the ergometer define the speed of the virtual bike. The load is in turn influenced by the virtual world environment, e.g. the gradient or the ground character. During a group training, patients must have the possibility to continue the training within their group even if they have a lower fitness level compared to other group members. Therefore we developed a corresponding load controlling algorithm: the dynamic group control. During a group training this provides a regulation of the ergometer load of a patient in a way that the patient is capable to work with a higher RPM, since the load is decreased when his health status turns critical. Thus, the patient is able to stay virtually near to the group cycling with a lower load but a higher RPM, and therefore a higher velocity, whereas other patients' load and RPM may vary.

Real-time: In order to create a sufficiently realistic virtual environment during the cycling within CordiAAL we have to meet real-time constraints. The rendering during a training shall not introduce significant delays, even during a group training, where the other bicycles of the participating patients have to be rendered also. So, the connection must not slow down the virtual training. These constraints also have to enable the mentioned controlling functions. Therefore we use Unity3D for rendering which works well with modern computers. In addition the position data of group members is communicated periodically using small UDP-messages.

Medical Requirements

Prophylactic and rehabilitation measure: A sufficient training effect must be guaranteed. We achieve this goal by providing several maps for virtual training environments, where each of them is categorized by a difficulty level. This leads to an optimal training for the patients with respect to their fitness level. Moreover the load control supports efficient and risk-reduced training. This results in improving the patients' sporting performance as well as their state of health.

Recording of vital data: For the acquisition of physical constitution in the course of cardiac rehabilitation and prophylaxis a broad spectrum of medical sensors is supported. They monitor the most important medical data, the heart rate, the respiration rate, the body temperature, the SpO2 level and the blood pressure.

Analyzing and visualizing vital data: The recorded vital data have to be analyzed by the application in order to control the ergometer load. The data have to be visualized on the screen. In addition, the vital data are also visualized in RehaWeb in a much more detailed way. This enables the cardiologist to examine these data during the training phase of each patient and therefore plan the next training sessions.

4 ARCHITECTURE

The project CordiAAL is based on a typical client/server system (see figure 1). On the one hand a web server with database access runs on the server-side. This server is responsible for the requests of the RehaWeb community while the data access is realized via a RESTful-API (Pautasso et al., 2008). On the other hand an application server acts as a communication interface between the different ergometer training applications. On this application server the virtual group information is processed via the position-tracking application as well as the real-time communication via the voice chat application.

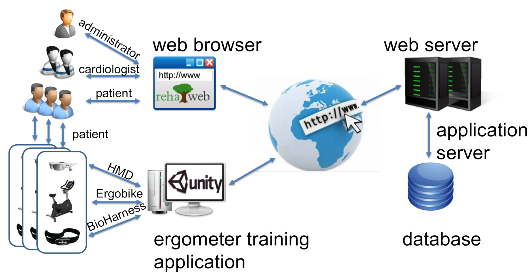

Figure 1: System architecture of the project CordiAAL

The client-side consists of three different groups of actors that interact with the system. Firstly the administrator realizes both the administration of each patient and the maintenance of the RehaWeb website. The cardiologists are able to define or to adjust vital parameters of their patients. Moreover, in RehaWeb they can supervise the recorded statistics. The patients immerse in the virtual world by using the ergometer and the HMD and are able to perform a virtual group training. Furthermore they can use RehaWeb's social network function in order to find out virtual routes or arrange a virtual group training.

The integrated devices comprise the virtual reality headset for displaying the immersive 3D world as well as a bicycle ergometer for controlling the load and a harness for recording the vital data (see figure 2). All of these components define a cyber-physical system (CPS) (Lee, 2008). In such systems the strict separation between the real and virtual world becomes neutralized. The physical environment gets recognized by the introduced sensors and is mixed with parameters of the virtual reality. The obtained information is processed and thus the physical environment is influenced correspondingly. For instance the revolutions of the pedals and the movement of the steering wheel control the velocity and the direction of the player respectively. On the other hand a mountain or bad ground covering in this world causes a higher adjustment of the ergometer's load, but always in consideration of the defined thresholds. The vital parameters ensure medically appropriate adjustments. Thus, this CPS combines the patient, the ergometer control and the Unity3D game engine to a virtual environment, that facilitates a group training and adjusts the individual performance levels.

Figure 2: Sensors environment of the system CordiAAL

4.1 Social Network

The RehaWeb system pursues the goal of motivating cardiac patients for sustainable training. Virtual group trainings on selected virtual 3D worlds can be planned in the RehaWeb community together with friends. The collected data are transmitted to the RehaWeb server and are reviewable there in the form of a training diary for both the patient and the medical staff. The patient is able to talk with other patients about the development of his own performance and other prevention-relevant topics in the forum.

The architecture of the social network RehaWeb consists of two layers. The first one comprises the server-side. The server component has been designed with a service-oriented and layered architecture. The Tomcat application server contains the community software as a Web2.0 user interface which is connected to a MySQL database. The server provides central storage and processing of all data. The access is provided via a RESTful-API. The second layer consists of the user's web browser. Java-ServerFaces 2.0 is used in order to generate dynamic HTML code.

The structure of the web portal RehaWeb is conceived hierarchically as a tree structure. The top level of the web portal is called the root. It is followed by the level of the main navigation and its subnavigation. In RehaWeb the level of the main navigation is represented as a horizontal bar above the green strip. The further sublevels are displayed as a subnavigation in the left column (see figure 3).

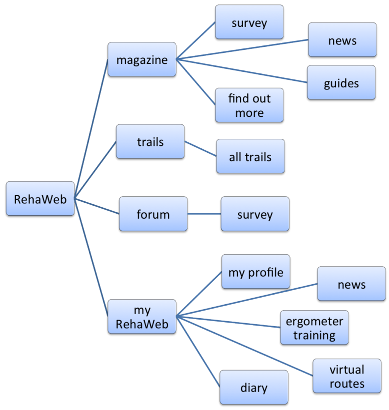

Figure 3: Portal structure of the website RehaWeb

4.2 Communication

The CPS CordiAAL shows three types of communication. These are described in the following.

The first one is the web communication. The communication between the web browser and the server is based on HTTP/HTML.

The second type is the access to the services of the server. These services are composed of the access, processing and storage of all necessary data before and after the training. The services are designed in respect of REST principles (Fielding, 2000). They are stateless and encapsulate every communication with the database. Each service class is responsible for one type of resource and provides methods according to the CRUD principle (Novick, 2008). JSON messages as the transport format are transmitted over HTTP.

The third type regards the time critical communication between the ergometer training applications. For the realization of a virtual group training, the current data concerning each patient's current state within the virtual world has to be exchanged via the position-tracking application. For instance the patient's ID and his position vector are transmitted. Another aspect concerns the audio communication between the patients of a group, realized by the voice chat application. On the application-side the open source .NET Audio and Musical Instrument Digital Interface (MIDI) library NAudio[6] has been used to facilitate a data stream. The audio samples are transmitted to the voice chat application over UDP messages and forwarded to the members of the group (see figure 4).

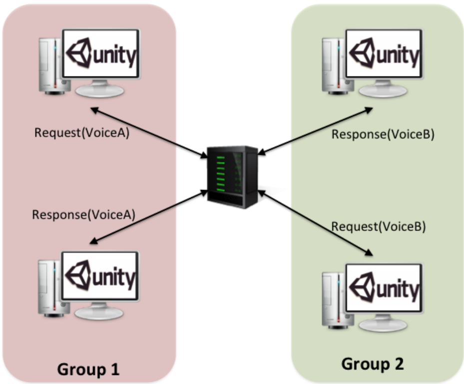

Figure 4: Voicemail distribution in different groups

4.3 Training

The training is executed either as a single training or as a group training. The challenge of this work is to perform a training in virtual groups and the medical load control of different patients. These aspects are explained in the following.

Medical Monitoring

The following data are collected for the medical supervision:

- ECG
- Respiration rate
- Body temperature
- SpO2
- Blood pressure

For the analysis of the SpO2 and blood pressure data we make use of the Corscience NiBP2010 sensor. The sensor communicates via an USB interface with our system. Moreover the Zephyr BioHarness3 sensor, which enables a precise recording of the vital parameters is used. The BioHarness3 communicates via a Bluetooth interface.

[6] http://naudio.codeplex.com

Load Control

Enabling the individual control of each patient's load within a group training needs to deal with several sensors and a load control algorithm.

Sensors & actors: The ergometer is the central entity for controlling the intensity during the training. Within our system we have used the ergometer Ergo_bike2000 of the company Daum Electronics. Via a RS232 interface data can be exchanged between the ergometer and the PC. These data are the current speed, the RPM and the load data to control the ergometer. The handle bars are modified in a way that they are rotatable and a realistic steering is achieved.

Controlling one person: The load control for one person is based on a typical control loop (Schulz, 2007) (see figure 5).

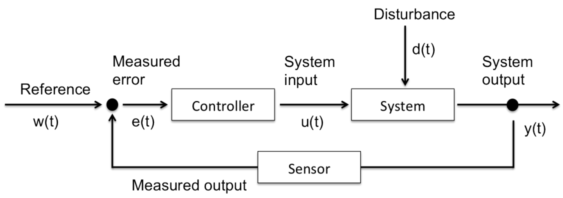

Figure 5: Control circuit of the load control

The regulation monitors the current heart rate value (y(t)) and compares it with the desired value (w(t)). Thus, disturbances (d(t)), for example slopes and overloads of the patient, are recognized and compensated (u(t)). The compensation is achieved by reducing or increasing the load.

Controlling a virtual group: In order to support virtual groups of patients with different fitness levels, the group control reduces the load of low fitness level patients. In detail, this means that a group member is not outpaced by the others due to his own lower fitness level. He has the possibility to cycle virtually near to the others. The load (d(t)) of a patient whose heart rate gets into the threshold area is reduced so that this patient is able to train with a higher RPM under less effort to retain the group velocity within the virtual world.

Therefore patients who have undergone a load reduction are able to cycle with the same RPM as before. Thus, this mechanism enables the weaker patients and the ones with a lower fitness level to stay virtually near the other group members.

Immersive Game Environment

For the purpose of realizing an immersive world we make use of a virtual reality head-mounted display as well as of a game engine for displaying the 3D world. Designing the application as a distributed system enables multiplayer games over the internet.

Virtual reality head-mounted display: To serve its purpose as a motivational tool and to improve the display quality of the 3D world a virtual reality head-mounted display is integrated into the system, in detail the Oculus Rift (developer version) is used. The head-mounted display has got a large field of vision and fast head-tracking sensors. The Oculus Rift provides a DVI and a HDMI input interface as well as an USB interface for transferring tracking data to the ergometer training application.

Unity3D: Unity3D is a complete development environment, designed to develop video games and rendering. The target platforms are Windows, Mac OS X, video game consoles and mobile phones. The development environment includes a visual editor, the C# editor Mono and different modules.

The main task of the visual editor is to create and manipulate 3D objects. The 3D objects can be created in programs such as Blender or Maya 3D. For details, logic and behavior components can be attached to 3D objects. Components define objects' properties like sound, look, material, texture, behavior and physical properties. Own components can be written in C#, JavaScript and Boo.

For the display of 3D objects Unity3D makes use of its own 3D engine. The 3D engine also handles the optimization of the scene so that the drawing is efficient.

For music and sounds Unity3D uses the FMOD library. Input devices such as mouse, keyboard and joystick can be integrated directly into Unity3D. Unity3D is free, but there is also a pro version. The pro version allows to write components in C++ and has some additional improvements in the 3D engine, the pro version supports dynamic light, shadow effects and more efficient rendering.

With Unity3D version 3.0 comes an Asset Store in which resources uploaded by other users, for instance 3D models, textures and sounds, can be bought or downloaded for free.

Virtual group dynamics: In the single training mode we have local access to the static 3D world. This mode requires no further information about other players. There is only communication to the server before and after the training. Before the training the information for the lobby, i.e. the currently training virtual groups or the planned training groups, is retrieved. After a training session the statistic data of the current session is sent to the server and stored in the database. In the group training mode each patient's local computer computes an own 3D-scenario, namely the view of the respective patient. However, the different scenarios are coordinated with each other. They use the same map and the positions of the players are communicated continuously. The corresponding distributed system is presented in figure 6.

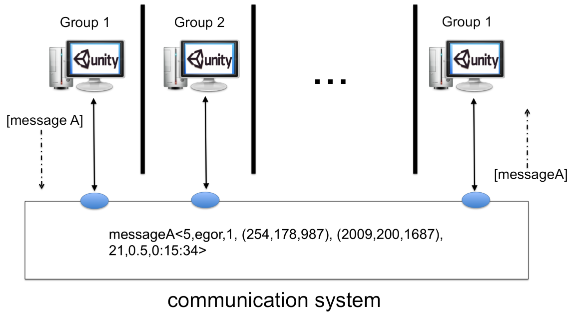

Figure 6: Behavior of the group dynamics on a distributed system

The 3D world is maintained on each computer, the other players are displayed dynamically according to the information about each group member. In order to obtain this information, the application exchanges messages in the following form:

- Patient ID
- Patient name
- Group ID
- Position vector (x, y, z)
- Direction vector (x, y, z)
- Velocity
- Position of the steering wheel
- Training time

The distribution of the messages to the corresponding group members is based on the group ID within the position-tracking application. The further data contained in the message are needed for displaying 3D objects locally on the ergometer training application.

5 APPLICATION

CordiAAL consists of two main applications: the RehaWeb website and the ergometer training

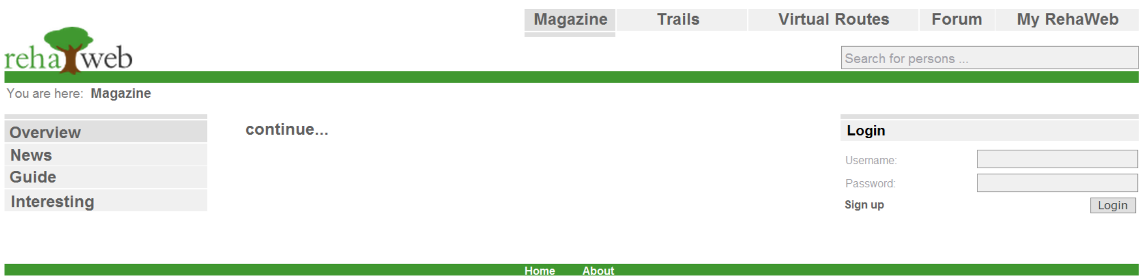

Figure 7: RehaWeb Home Surface

application. The ergometer training application is responsible for the whole training sessions of the patients and the RehaWeb website for user administration and community functions.

5.1 RehaWeb

During the development of the CordiAAL project the existing RehaWeb application was extended and adapted, so that it is now possible to combine both applications. The RehaWeb website provides functionality for three types of user groups: patient, cardiologist and administrator. Every group has got different permissions within RehaWeb.

Patient: Patients can log in after registering on RehaWeb. After log in they can look at their last workout statistics.
They can arrange to meet with other patients for a virtual group workout within the CordiAAL ergometer training application. Furthermore it is possible to communicate in a forum to exchange information and experiences with other patients. Moreover they can exchange private messages with friends inside the RehaWeb community.

Cardiologist: Cardiologists can use RehaWeb to manage the vital parameters of their patients (see fig. 8). This is a very important function, so that an individual and best possible workout is guaranteed for each patient. It helps to avoid overloads of the patients. The cardiologists are able to set the values for the heart rate, respiration rate, body temperature and SpO2. Initial values have to be set for each patient after examination by the clinic.
Additionally they have permissions to view and supervise detailed training statistics of all their patients. Figure 9 shows an excerpt from a sample statistic which has been recorded during a training session.

Administrator: The administrator has got the permissions to manage all the users of RehaWeb. Only he is able to add a new virtual route which the patients can choose for their virtual training within the ergometer training application.

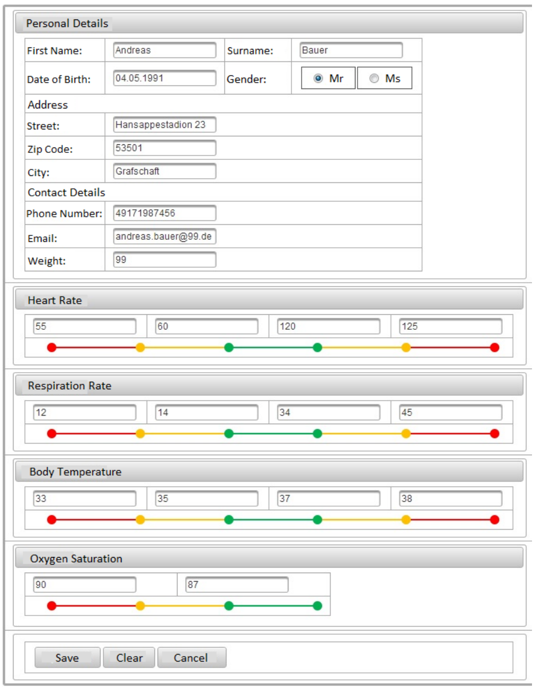

Figure 8: Vital Parameters Surface

5.2 Ergometer Training Application

The ergometer training application is the main application of the CordiAAL system and responsible for the training sessions. It controls the workout, manages the sensors and takes care of the health status of the training members. A training session can be divided into three main sections: Training Preparation, Training Execution and Training Conclusion.

Training preparation: First of all after starting the application, the patients log in to the ergometer training application with their user data from

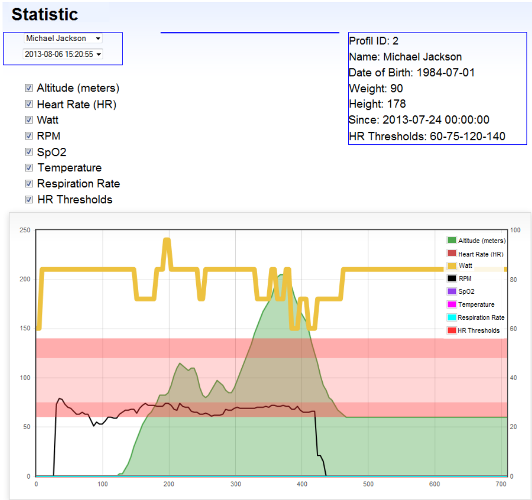

Figure 9: Detailed Statistic Surface

RehaWeb. After a successful login the patients are able to view their last workout statistics or they can choose between a single and a group training session. By selecting a group training it is possible to start a workout together with up to six other patients at the same time using the same virtual route. In this training mode all patients can see each other like in a multiplayer game. The other participants are covered in different colors and they are able to communicate via voice chat. After pushing the training start button, the patients are asked to connect all sensors and devices. The system waits until the patients have connected all sensors. In an overview all connectable sensors and devices are displayed with their connection status.

Before the workout starts, the patients have to

Figure 10: Training Settings

configure the settings of the training. They can select a virtual route which they want to drive in, set the duration of the workout and in group training mode they can set the maximum number of other patients driving with them (see fig. 10). It is also possible to join an existing training instead of creating a new one. By clicking on a displayed training from the list, a short status information is shown. It gives information about the remaining time, which virtual route is used and how many other patients participate in this workout. The patients get only training sessions displayed they are able to join. Either the training is a public one or the patient has previously arranged it on RehaWeb. If they want to join one of the current training sessions they simply have to select one and click on the start button. The workout starts immediately. As well there is a menu item reachable from the main menu, where the patients get an overview list of training sessions which will start in the future.

Figure 11: Workout Screen

Training execution: From beginning to end of a training session the application records all sensor data like heart rate, SpO2, temperature, speed, distance, time and rpm in an interval of one second. Some of this information is displayed on the screen during the training. So the patients can see directly what the current load in watt is, the speed in km/h, meters of the altitude profile and the driven distance. On the left side of the display the names of the other group members and their colors are shown. But the most important information displayed is the heart rate status bar. It is a big status bar in top of the screen, which is corresponding to the current heart rate of the patient (see fig. 12). Thus the patients can easily see if they perform their training in the right way. The status bar is colored from green to red. These scale correlates to the settings the cardiologist managed on the RehaWeb website. Training inside the green range is optimal. The yellow and red range indicate to drive faster or slower to get back into the green area. Additionally a message occurs on the screen with instructions. If the physical load is still too high, the system will regulate the load of the ergometer down, until the heart rate of the patient will be out of the red area. After the predefined time span the workout will finish automatically, but the patient is capable to abort the training session by clicking an exit button before the training time is elapsed.

Figure 12: Heart Rate Status Bar

Training conclusion: After the workout, the patients are asked to specify a Borg value (Borg, 1970) for the training, which is an important clue for the cardiologist about the subjective intensity of the training (see fig. 13). Thereafter all recorded data

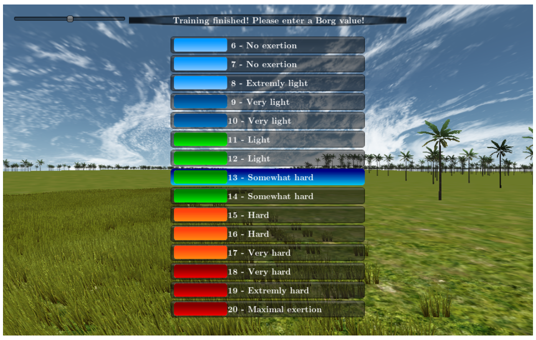

Figure 13: Surface to enter the Borg Value

from the sensors and the application are transmitted and stored in a database hosted by the CordiAAL server. If it is impossible to transmit the data to the server, e.g., because of a broken internet connection, the recorded data will be saved on the local hard disk. Next time the ergometer training application is started the application tries to submit the data again. Finally a short summary of the current training session results together with average values like heart rate, distance and time are displayed (see fig. 14).

Figure 14: Workout Summary

6 EVALUATION

The evaluation aims at two different aspects: Analyzing how far the CordiAAL system assists the users in the execution of a training session and increasing the motivation for a sustainable training. Secondly, verifying the application in terms of design, usability and ergonomics of the user interface.

In the evaluation process, the subjects performed an afore designed scenario, which relates to a normal use of the software. The scenario comprises a training session, inspecting the statistics and a review of the completed session. During the training session, it will be analyzed how the displayed information affects the subjects, how they experience the virtual environment through the virtual reality head-mounted display, and how far the virtual training affects the increase of motivation. Here, an important aspect is whether a virtual group training influences the motivation and how it stimulates the subject's ambition, so that training sessions are no longer felt as a liability but more as a game.

To evaluate the aforementioned aspects, a questionnaire was presented to the subjects after the training. The questions were divided into three categories and rated on a scale from one to five (1 = "the statement is not true", 5 = "the statement is true"). First, the subjects were asked to answer questions for self-assessment, these questions helped to determine how motivated the subjects are in doing sports. In the second category of the questionnaire, subjects were asked to rate the usability of the system. At the end of the test subjects were asked to rate the virtual training and specify whether this type of training could increase their motivation.

Overall 10 participants, including 2 women and 8 men were tested in the age range of 25 years up to 36 years. The sequence of execution took about 30 minutes to complete, with two training sessions by 10 minutes.

In order to present the usability evaluation results, five categories were defined (see figure 15). As you can see, the software is considered as user-friendly, an average value of 3,7 out of 5 was achieved. One of the most important aspects of this case was to make the software as intuitive as possible, so long learning phases are avoided and this barrier pulls no reduction in motivation.

To evaluate the training, the subjects self-assessed their sportiness and their general sport-related motivation to conclude how far the training in the virtual environment could increase their motivation. To illustrate the influence of the training with CordiAAL we have taken two aspects into account. The moti-

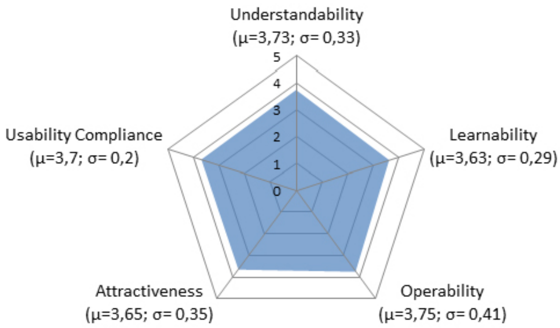

Figure 15: Evaluation of the usability questions by categories "Understand Solutions, Learnability, Operability, Attractiveness, Usability Compliance"

vation for doing sports with and without any general technical aids, and the same with CordiAAL as a specific technical aid. Figure 16 clearly illustrates that the subjects have difficulty doing sustainable sporting activities and also the willingness of using aids is low. In turn, the increasing motivation through the virtual training is clearly evident. An increased value for the readiness to use CordiAAL as a technical aid for regular sport activities was also indicated. The most important motivation factor was thereby the training in a virtual group. It was stated that the training and communication with other group members minimize the effort of training and increase the ambition.

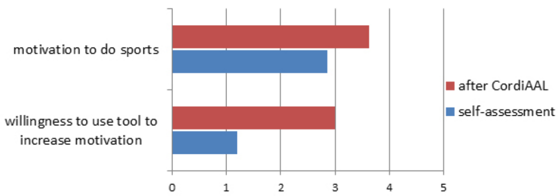

Figure 16: Evaluation of the questions of motivation and willingness to use the aids, divided according to data obtained from the self-assessment and evaluation after training with CordiAAL.

7 CONCLUSION

The user study clearly demonstrates that the main objectives of the CordiAAL system were achieved, realizing a playfully ergometer training which motivates users to a regular physical activity, bringing users with different fitness levels together and to give them safety at the same time.

This is done by a permanent monitoring of vital data and an adjustment of the ergometer load based on these data. Since the study was not conducted with subjects with heart disease, for ethical reasons, the question of the decrease of anxiety remains open.

The next stage in the evaluation would be a long-term study to check if the motivation stays high-leveled in a long-term use.

REFERENCES

Anderson, F., Annett, M., and Bischof, W. F. (2010). *Annual Review of Cybertherapy and Telemedicine 2010*. Studies in Health Technology and Informatics.

Balady, G., Williams, M., Ades, P., Bittner, V., Comoss, P., Foody, J., Franklin, B., Sanderson, B., and Southard, D. (2007). Core components of cardiac rehabilitation/secondary prevention programs. *Circulation*, 115(20):2675–82.

Bjarnason-Wehrens, B., Held, K., and Karoff, M. (2006). Herzgruppen in Deutschland Status quo und Perspektiven. *Herz*, 31:559–565.

Bjarnason.Wehrens, B., Drsch, M., Gielen, S., Halle, M., Hambrecht, R., and Kindermann, W. (2009). Leitlinie krperliche aktivitt zur sekundrprvention und therapie kardiovaskulrer erkrankungen. *Clinical Research in Cardiology Supplement (CRICS)*, pages 1–44.

Borg, G. (1970). Perceived exertion as an indicator of somatic stress. *Scandinavian journal of Rehabilitation Medicine*, 2:92–98.

Boulos, M. N. K. and Yang, S. P. (2013). Exergames for health and fitness: the roles of gps and geosocial apps. Technical report, International Journal of Health Geographics.

Busch, C., Litvina, A., and Willemsen, D. (2009). Kardiale Telerehabilitation auf Basis einer flexiblen Plattform für verteilte Systeme - das OSAmI-D Projekt. *e-Health*, pages 218–221.

Caprani, N., O'Connor, N. E., and Gurrin, C. (2012). Touch screens for the older user. In Cheein, D. F. A., editor, *Assistive Technologies*, chapter 5. InTech.

Dohndorf, O., Gring, A., Krumm, H., Schneider, A., Sommer, A., Sladek, S., Busch, C., Hoffmann, J.-D., and Willemsen, D. (2012). Rehaweb - an information system for cardiologic rehabilitation assistance in the third phase. Technical report, TU Dortmund University.

Eifert, G. H., Thompson, R. N., Zvolensky, M. J., Edwards, K., Frazer, N. L., Haddad, J. W., and Davig, J. (2000). The cardiac anxiety questionnaire: development and preliminary validity. In *Behaviour Research and Therapy*, volume 38, pages 1039–1053. Elsevier Ltd.

Fielding, R. T. (2000). *Architectural styles and the design of network-based software architectures*. PhD thesis, University of California. AAI9980887.

in Deutschland aktuell Telefonischer Gesundheitssurvey (GEDA) des Robert-Koch-Instituts, G. (2009/2010). Gesundheit in deutschland aktuell - telefonischer gesundheitssurvey (geda) des robert-koch-instituts: Durchschnittliche sportliche aktivitt pro woche (anteil der befragten in prozent).

Kotseva, K., Wood, D., Backer, G. D., Bacquer, D. D., Pyoeraelae, K., and Keil, U. (2009). Cardiovascular prevention guidelines in daily practice: a comparison of euroaspire i, ii, and iii surveys in eight european countries. *The Lancet*, 373(9667):929 – 940.

Lampert, C., Schwinge, C., and Tolks, D. (2009). Der gespielte ernst des lebens: Bestandsaufnahme und potenziale von serious games (for health). *Zeitschrift fr Theorie und Praxis der Medienbildung*, 15/16:1–16.

Lee, C., Folsom, A., and Blair, S. (2003). Physical activity and stroke risk: a meta-analysis. *Stroke*, 34(10):2475–81.

Lee, E. A. (5-7 May 2008). Cyber physical systems: Design challenges. *Object Oriented Real-Time Distributed Computing (ISORC), 2008 11th IEEE International Symposium on*, pages pp.363–369.

Nocon, M., Hiemann, T., Müller-Riemenschneider, F., Thalau, F., Roll, S., and Willich, S. N. (2008). Association of physical activity with all-cause and cardiovascular mortality: a systematic review and meta-analysis. *Eur J Cardiovasc Prev Rehabil*, 15:2239–246.

Novick, A. (2008). Implementing crud operations using stored procedures: Part 1.

Pautasso, C., Zimmermann, O., and Leymann, F. (2008). Restful web services vs. "big"' web services: making the right architectural decision. In *Proceeding of the 17th international conference on World Wide Web*, WWW '08, pages 805–814, New York, NY, USA. ACM.

Sattelmair, J., Pertman, J., Ding, E., Kohl 3rd, H., Haskell, W., and Lee, I. (2011). Dose response between physical activity and risk of coronary heart disease: a meta-analysis. *Circulation*, 124(7):789–95.

Schulz, G. (2007). *Regelungstechnik 1 Lineare und Nichtlineare Regelung, Rechnergesttzter Reglerentwurf*. Oldenbourg Wissenschaftsverlag GmbH.

Shahsavari, H., Shahriari, M., and Alimohammadi, N. (2012). Motivational factors of adherence to cardiac rehabilitation. *Iranian Journal of Nursing and Midwifery Research*, 17:7.

Statistisches Bundesamt (2008). Herz-/Kreislauferkrankungen verursachen die höchsten Krankheitskosten. Wiesbaden.

Statistisches Bundesamt (2011). 2011: Todesflle 2011 leicht rcklufig hufigste todesursache herz-/kreislauferkrankungen. Wiesbaden.

Yusuf, S., Hawken, S., Ounpuu, S., Dans, T., Avezum, A., Lanas, F., McQueen, M., Budaj, A., Pais, P., Varigos, J., and Lisheng, L. (2004). Effect of potentially modifiable risk factors associated with myocardial infarction in 52 countries (the interheart study): case-control study. *Lancet*, 364(9438):937–52.