A New Home-Based Training System for Cardiac Rehabilitation

Christian Menard and Raimund Antonitsch

Carinthia University of Applied Sciences, Department of Medical Information Technology
Primoschgasse 10, 9020 Klagenfurt, Austria
{C.Menard,R.Antonitsch}@cuas.at

Abstract. Epidemiological studies show that regular exercise sessions are the most important pillars in the field of cardiologic rehabilitation. For many diseases a correctly implemented strength training therapy can improve physical fitness and health. In this work a novel pictorial strength measurement method for home-based training is presented. In order to reduce the risk of injury during the training session, simple elastic bands can be used as training devices. Such systems can make therapeutical processes more effective while simultaneously reduce the overall costs of therapy.

Keywords: Ambient Assisted Living, Home Monitoring, Home based Training.

1 Introduction and Motivation

Based upon epidemiological studies we know today that structured, regular exercise sessions are the most important pillars to the prevention and rehabilitation of society's most widespread disease, the metabolic syndrome [1]. Pedersen and Saltin describe in great detail how sport and exercise can be used as therapies and treatments for diseases that are associated with the metabolic syndrome [2]. In all of these diseases specialized, correctly implemented strength training therapy improved the individuals' psycho-socially and bodily well-being as well as their physical fitness, reduced the number of medical complaints and stopped or even reversed the advancement of these diseases. Due to these reasons new innovative technologies for home-based training need to be developed that not only keep people healthier longer but also make the therapeutical processes in treating health problems more effective while simultaneously reducing the costs of therapy.

Especially for the elderly as well as people with coronary heart disease carefully monitored weight lifting programs are becoming very important therapeutical methods [3]. A precise validation of the progress of the training is currently only available in outpatient settings and with expensive strength measurement devices. Costs compared to normal stationary stays at therapy centers can be greatly reduced on the one hand while on the other hand it is easier for the elderly to participate in medically directed health training programs.

K.S. Nikita et al. (Eds.): MobiHealth 2011, LNICST 83, pp. 358–365, 2012.

This work will give a short overview to cardiac rehabilitation and the developed home based training system and will then focus on the methods for the pictorial strength acquisition.

2 Strength Training for Cardiac Rehabilitation

Heart diseases, also known as cardiac diseases, are the major cause of death in Austria. Four deaths of ten were due to heart diseases in 2011. The most prevalent heart disease is the heart attack, which belongs to the group of coronary diseases, caused mainly by the calcification of coronary vessels.

According to the World Health Organization (WHO) the aim of cardiac rehabilitation is the stabilization and prevention of heart diseases [4]. In addition to the preservation of life cardiac rehabilitation also provides health economical benefit such as decreases in hospital stays and reduction of blood pressure lowering medication.

For many years endurance training was the key aspect in cardiac rehabilitation. But recently results of several studies have shown that moderate strength training is becoming more and more important. Strength training helps to improve stability and coordinative skills, which are essential for elderly to avoid falls. Especially bedridden patients after a surgery are understrength and therefore strength training is an important step to regain independency and sense of well-being. Furthermore, bone density increases due to well-directed strength exercises. For these reasons strength training should be an integral part of cardiac rehabilitation [5].

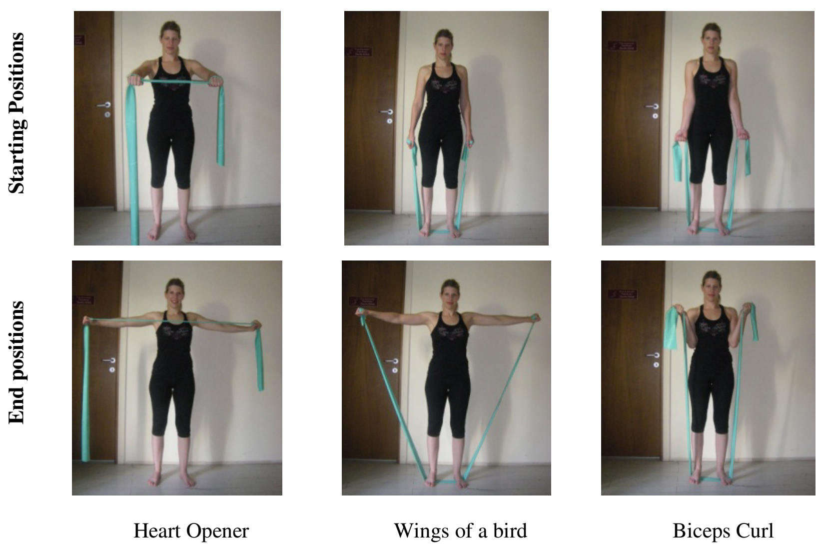

Fig. 1. Three training exercises used for home based training

The Thera-Band® is an established training device for cardiac rehabilitation. The multitude of possible exercises and the low price make it a popular choice. These bands are available with different strength levels, indicated by the color. Patterson et al. describe the material properties depending on color and strain in great detail [2]. In this work three typically exercises, which are used in cardiac rehabilitation, were used to test the proposed method (see Fig. 1).

Training exercises have a detailed description with exact starting and end positions. For each patient a specific trainings profile can be specified with all necessary parameters like type of the exercise, duration, set count and the color of the used band. Using these parameters the therapist is able to adapt the training program to the actual situation of the patient. In the field of home-based training exercise monitoring and immediate feedback to the patient is essential for the training success. Especially for people who have no training experience the developed measurement system guarantees that the spent force is adequate and does not stress the patient.

3 System Overview: Home-Based Training

In the framework of the research project "Health@Home" a home-based training system is developed. It is designed as a simple user friendly system to be used directly in the user's living room [6]. In Fig. 2 an overview of the home-based training system is depicted. A *Training-Coach* downloads the user-specific training profile and starts with the training instructions. For all exercises standard elastic bands are used. The measured pulse and the strength exerted on the band are continuously measured and transmitted via Bluetooth to the *Training-Coach*. The pulse is recorded by means of a standard pulse sensor (e.g. Polar).

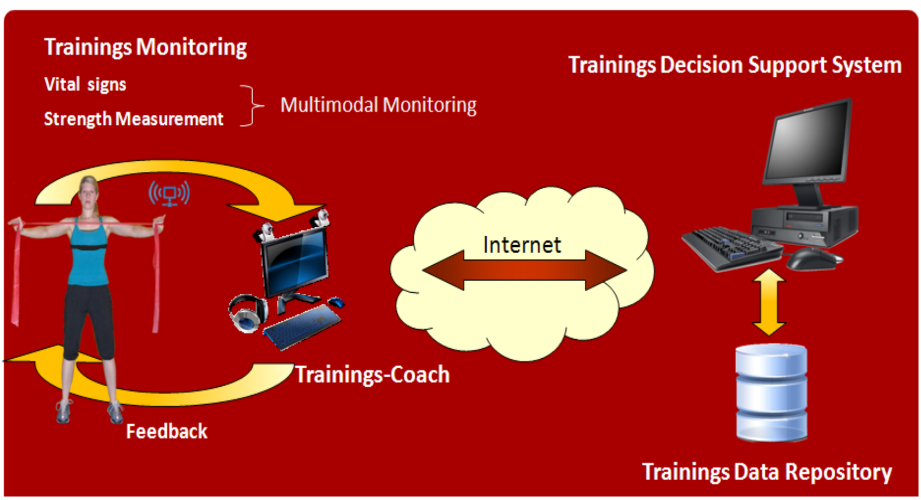

Fig. 2. System overview of the home-based training system

During the training the *Training-Coach* provides the patient with audio feedback about the current training status. Time series data of both sensors are chronologically synchronized for the entire training session, transmitted and stored in the *Training Data Repository* at the therapy center. Thus, therapists have the possibility via the *Decision Support System* (DSS) to monitor and control each training session individually. Using the *DSS* the therapists have the possibility to visualize and analyze all recorded training sessions in detail.

In order to have a flexible and simple training setup a pictorial strength measurement method was developed. This pictorial strength measurement reduces the risk of injury tremendously, compared to physically mounted sensors that may hurt the patient during the exercise.

4 Pictorial Strength Measurement

The strength measurement is realized via a visual analysis of the training session using a calibrated stereo camera setup (see Fig. 3). A simple coding technique using predefined ball markers on the band is used to calculate the strength during the training session. So the elastic band itself is the measurement device and physically mounted force sensors are obsolete. The ball markers are detected and the extension of the band can be used to calculate the strength.

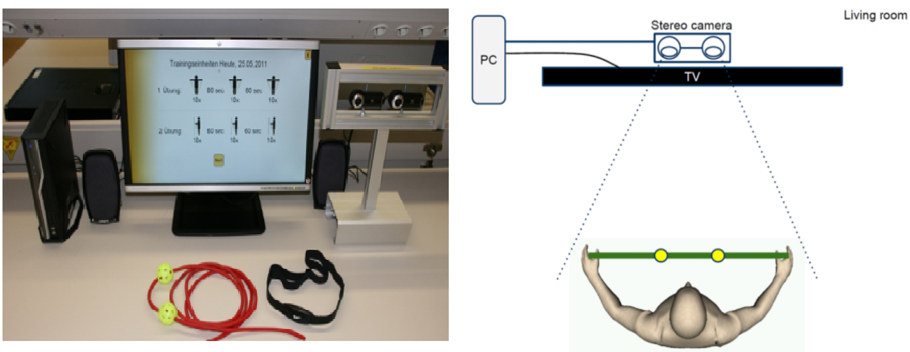

Fig. 3. Equipment of the home-based training system and a schematic overview

The larger the distance between the markers the higher is the strength. By using the stereo setup the 3D position of the band and the markers can be reconstructed, thus making the strength measurement more robust. Due to the fact that exclusively standard hardware is used, the system is designed as a low cost system.

The workflow of the pictorial measurement algorithm is depicted in Fig. 4. For most of the process tasks standard image processing methods could be used [7][9].

Fig. 4. Process of the pictorial strength measurement

First the image area is segmented according to the color of the mounted ball markers so that pixels with the same color as the balls remain [10]. In order to avoid fail detections only moving pixels are filtered out on the basis of motion information [8][9]. A blob detection based on a certain blob size is then used to determine the position of the ball markers. Corresponding balls in the left and right image together with the stereo calibration parameters are used for 3D reconstruction. The 3D positions of the balls are transformed to real-world distances which are then used for strength calculation.

In order to determine the strength out of the measured marker distances, a strength calculation model was determined depending on the different bands. Fig. 5 shows force values for different bands depending on the elongation.

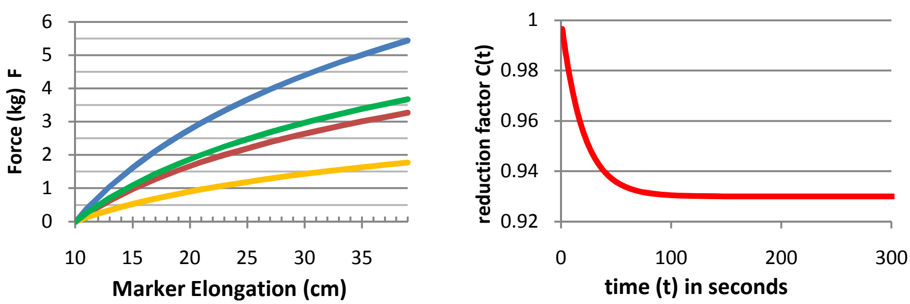

Fig. 5. Strength calculation model with time-dependent force characteristic

The force

$$F(t) = C(t)\, B_{\text{color}} \ln(\varepsilon), \tag{1}$$

needed to stretch the band by the elongation ΔD is time-dependent and it is a nonlinear function of the current strain $\varepsilon = \Delta D / D_0$, where D_0 denotes the marker distance in the zero-force configuration. The matter constant B_{color} accounts for the mechanical properties of the materials used for the different band types. Below the constants B_{color} of the four different, color coded, band types are listed.

$$\begin{aligned} B_{\text{blue}} &= \mathit{4}, \\ B_{\text{green}} &= \mathit{2.7}, \\ B_{\text{red}} &= \mathit{2.6} \text{ and} \\ B_{\text{yellow}} &= \mathit{1.3}. \end{aligned} \tag{2}$$

Due to the fact that the strength of the band reduces over time exponentially a force reduction factor $C(t)$ is modeled by

$$C(t) = (1 - C_s)e^{-t/\tau} + C_s \ , \quad (3)$$

whereby τ is the time constant of the relaxation process in minutes and C_s defines the steady state factor at the end of the relaxation process. Several tests on different bands using the force sensor have shown to use the values $C_s = 0.93$ and $\tau = 20$.

5 Results

The home based training system was tested for all three exercises with several patients. In Fig. 6 the user interface of the home based trainings system is depicted. The *Training-Coach* application can be installed on the standard PC and was designed as low cost system, thus the components are available for approximately 400 € (excl. TV).

The patient can see the video together with the actual pulse and the calculated strength on the screen. During the training all relevant data are transferred to the *Trainings Data Repository*. So the therapists are able to analyze the training and if necessary adapt the training profile of the patient. The progress bar indicates the actual progress during the exercises. In addition the *Training-Coach* permanently supports the user with audio feedback about the actual trainings status like the tempo or how many exercises are missing.

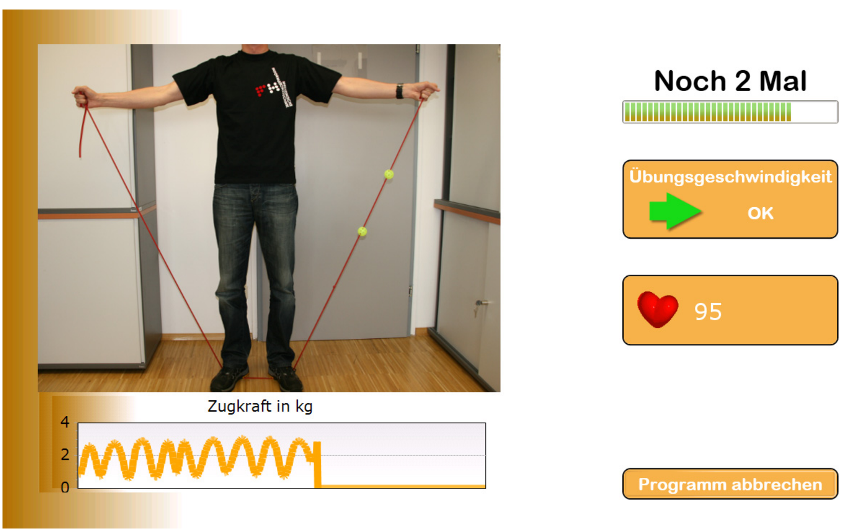

Fig. 6. User interface showing a user during the training. The strength together with the pulse is visualized.

In order to evaluate this new pictorial strength measurement method a physically mounted force sensor was used on the band to collect ground truth strength data. The visual strength measurement method was tested for the three different exercises using the measured ground truth data. With the visual sensed data on the one hand and ground truth data on the other hand, the underlying calculation model could be calibrated.

(a) (b)

Fig. 7. Force sensor (a) force sensor with case and (b) mounted on the band

For each band a so-called rating curve could be determined in order to fit best to the physical behavior of the specific band. During the training the strength could be calculated at 20fps with an accuracy of ±5% to the physical force sensor. Fig. 8 shows both the strength obtained by the force sensor and the calculated strength with the presented method.

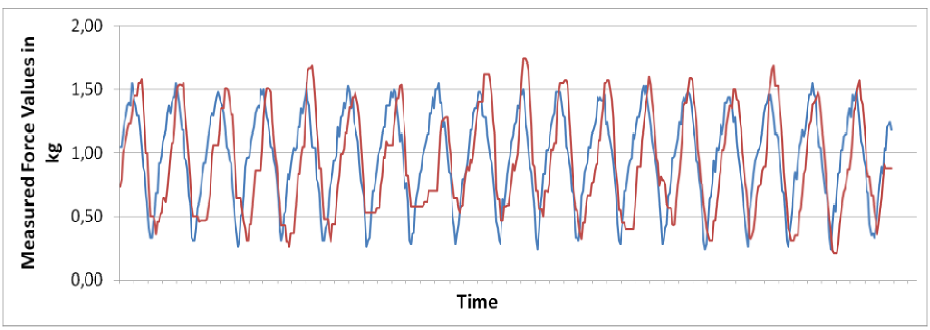

Fig. 8. This chart shows a comparison between force data obtained by the physically mounted sensor (blue) and the calculated strength (red)

6 Conclusion

A new pictorial strength measurement method was presented to be used in the field of cardiac rehabilitation. Using this system home based training can be performed very easily in the patient's home environment, thus the proposed method offers a new methodology in the field of home based training. The motivation effect on the one hand and the facility to track the training progress on the other hand are the major advantages. Furthermore the risk of injury is reduced tremendously compared to other measurement methods that depend on mounted sensors. Future steps are directed towards an infrared setup to be more flexible and robust against varying light conditions. In addition the integration of this method into an easy to use training application and a field study with over 80 patients is planned in the near future.

References

1. Maxwell Mark, S., et al.: Metabolic Syndrome and Related Disorders, vol. 6(1), pp. 8–14. Springer, Heidelberg (2008)
2. Pedersen, B.K., Saltin, B.: Evidence for prescribing exercise as therapy in chronic disease. Scandinavian Journal of Medicine & Science in Sports 16(s1), 3–63 (2006)
3. O'Connor, G.T., Buring, J.E., Yusuf, S., Goldhaber, S.Z., Olmstead, E.M., Paffenbarger Jr., R.S., Hennekens, C.H.: An overview of randomized trials of rehabilitation with exercise after myocardial infarction. American Heart Association. Circulation 80, 234–244 (1989)
4. Balady Gary, J., et al.: A Scientific Statement From the American Heart Association Exercise. Cardiac Rehabilitation, and Prevention Committee, Circulation 115, 2675–2682 (2007)
5. Jonas, S., Phillips, E.: ACSM's Exercise is Medicine™ A Clinician's Guide to Exercise Prescription Softbound
6. Menard, C., Hayn, D., Traninger, H.: Gesundes Altern durch Heimbasiertes Training. In: Forschungsforum der Oesterreichischen Fachhochschulen (2011)
7. Bradski, G., Kaehler, A.: Learning OpenCV - Computer Vision with the OpenCV Library. O'REILLY (2008)
8. Cheung, S., Kamath, C.: Robust techniques for background subtraction in urban traffic video. Visual Communications and Image Processing 5308(1), 881–892 (2004)
9. Sonka, M., Hlavac, V., Boyle, R.: Image Processing, Analysis, and Machine Vision. Thomson (2008)
10. Schanda, J.: Colorimetry - Understanding the CIE System. Wiley (2007)