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A NEW APPROACH TO STRENGTH MEASUREMENT FOR CARDIOLOGIC REHABILITATION

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Kurzfassung

Epidemiologische Studien belegen wie Sport zur Behandlung von kardiologischen Erkrankungen eingesetzt werden kann [6]. Ein dosiert eingesetztes Krafttraining kann den Fitness- aber auch den Gesundheitszustand verbessern. In dieser Arbeit wird ein bildbasiertes Verfahren zur Kraftmessung für heimbasiertes Training vorgestellt. Durch dieses Verfahren kann die Verletzungsgefahr minimiert und einfache am Markt erhältliche elastische Bänder als Trainingsgeräte verwendet werden. Der Therapieprozess kann somit effektiver und kostenreduzierender durchgeführt werden.

Abstract

Epidemiological studies show that regular exercise sessions are the most important pillars in the field of cardiologic rehabilitation [6]. For many diseases a correctly implemented strength training therapy can improve physical fitness and health. In this work a novel visual strength measurement method for home-based training was developed. 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* – Home Monitoring, Home-Based Training, 3D Reconstruction**

1. Introduction

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 [3]. 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 [6]. In all of these diseases specialized, correctly implemented strength training therapy improved the individual's psycho-social 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 reduce the costs of therapy [1,4].

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Especially for elderly as well as people with coronary heart disease carefully monitored weight lifting programs are becoming very important therapeutical methods [2,4,5]. 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.

1. 1. Training exercises

A common training device for therapeutical weight lifting is the so-called Thera-Band®. It offers the possibility to perform a variety of different exercises types. Thera-Bands are color-coded, different colors define different strength intensities. Therefore the trainer can adapt the intensity by choosing the right color. For the home based training the following training exercises are used, which are most common in cardiologic rehabilitation (see *Figure 1*).

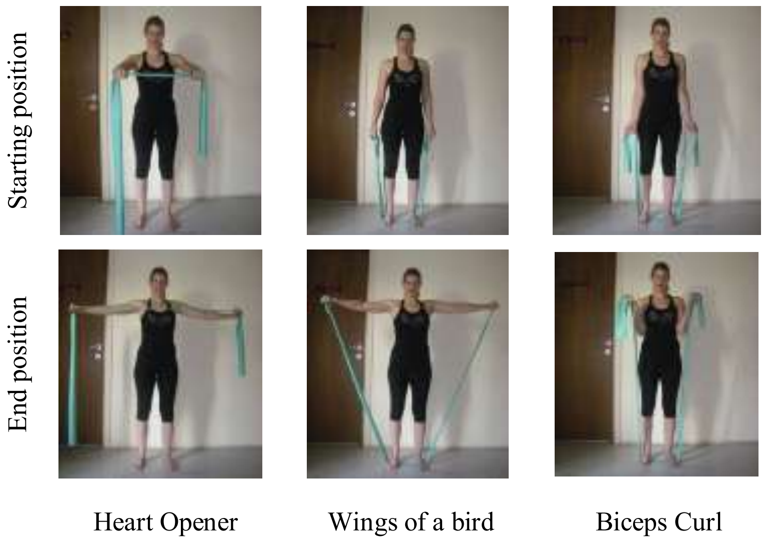


Figure 1: Training exercises

For each exercise a detailed description is available with the exact starting and end positions. For each patient a specific trainings profile is designed. In this profile all necessary parameters like type of the exercise, duration, set count and the color of the used band are stored in the system. Using these parameters the therapist is able to adapt the training program to the actual situation of the patients.

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 strength measurement system guarantees that the intensity is adequate and does not stress the patient. Strength measurement also motivates the patient.

2. Methods

In order to have a flexible and simple training setup a visual strength measurement method was developed. During the training vital parameters, like heart rate, blood pressure, as well as the strength that is spent during the exercise, are recorded. This image based strength measurement reduces the risk of injury tremendously, compared to physically mounted sensors that may hurt the patient during the exercise. The monitored data are used to generate an audio-visual feedback for the patient on the one hand, while on the other hand the therapists and physicians can use these data to check the training progress. The vital parameters (heart rate and blood pressure) are monitored by means of wireless capable devices directly on the patient.

The strength measurement is realized via a visual analysis of the training session using a calibrated stereo camera setup (see *Figure 2*). A special coding technique using predefined markers on the Thera-Band® is used to calculate the strength during the training session. So the Thera-Band® itself is the measurement device and physically mounted sensors are obsolete. The markers are detected and the extension of the band can be used to calculate the strength. The larger the distance between the markers the higher is the strength.

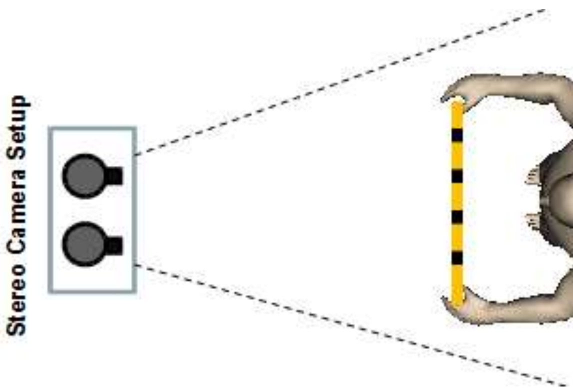
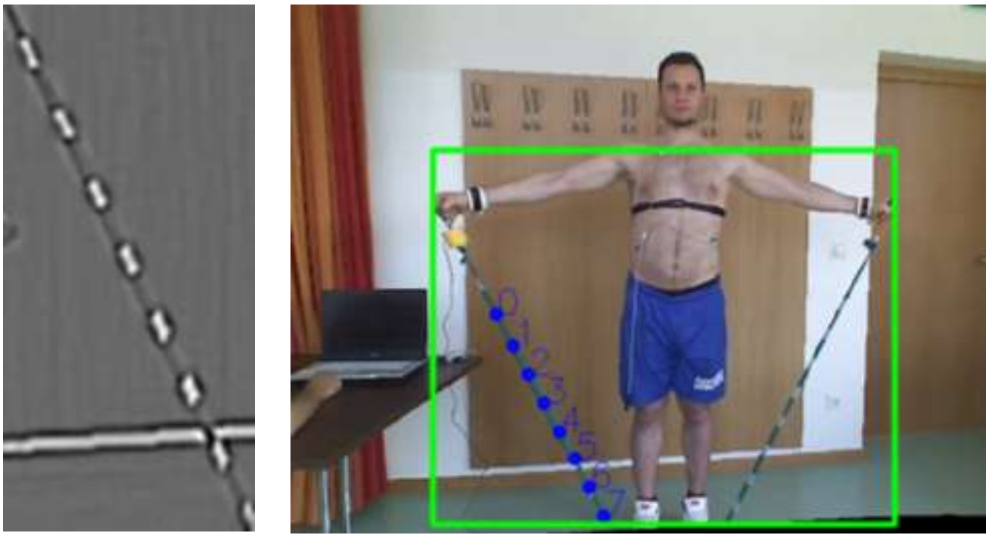


Figure 2: Stereo camera setup

By using the stereo setup the 3D position of the Thera-Band® 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 for the strength measurement is shown in *Table 1* in more detail.

Table 1: Strength measurement workflow

Steps of the algorithm	Description
1. Foreground Detection	The image area where the person is moving is separated from the static background to avoid false detection in wrong image regions.
2. Color Filtering	The remaining image part is color filtered according to the Thera-Band® used. Only regions of a pre-defined color range remain.
3. Thera-Band® Detection	A Hough Transformation of the remaining pixels is used to detect the Thera-Band® position in the image.
4. Marker Detection	The marker positions are determined by using blob detection in the region of the detected Thera-Band®.
5. 3D Reconstruction	Corresponding marker points in the left and right image together with the stereo calibration parameters are used for 3D reconstruction and distance measurement.
6. Strength Calculation	The marker distance together with the model parameters are finally used to calculate strength during the training.



(a) (b)

Figure 3: (a) Marker detection and (b) Foreground detection with detected markers

After color filtering, the detected region of the band is used for a blob detection using a Laplacian kernel *(Figure 3 (a))*. Markers are detected by means of a threshold and eliminating peaks that are not in the area of the detected Thera-Band® (step 3). *Figure 3 (b)* shows a detection result for one image frame. The green rectangle illustrates the determined foreground (dynamic image area) and the numbered blue points show the position of the detected markers points. The mounted sensor at the right hand was used to gather ground truth strength data for calibration and evaluation purposes.

2. 1. Model 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 therabands. *Figure 4*Figure shows force values for different therabands depending on the marker distance.
The force

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

needed to stretch the theraband 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 theraband types. Below the constants B_{color} of the four different, color coded, theraband types are listed.

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

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

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$$C(t) = \frac{F(t)}{F_0} = (1 - C_s)e^{-t/\tau} + C_s \; , \qquad (3)$$

whereby $F_0 = F(0)$ is the initial force at the beginning of the expansion. 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 = 6 and τ= 10.

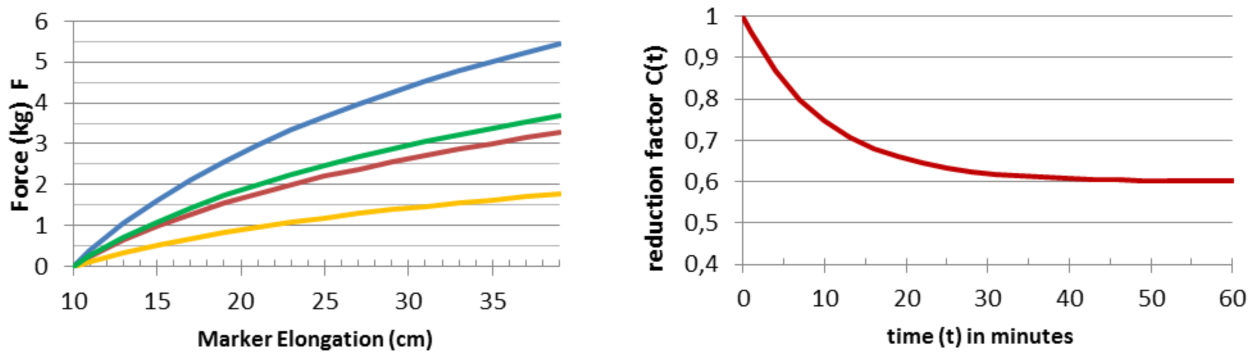

Figure 4: Strength calculation model with time-dependent force characteristic.

In order to evaluate this new visual strength measurement method a physically mounted sensor was used on the band to collect ground truth strength data (see *Figure 5*).

(a) **(b)**

Figure 5: Force sensor (a) force sensor with case and (b) mounted on the band.

3. Results

The visual strength measurement method was tested for three different types of 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. This is necessary because of the non-linear extension behavior of the different colored Thera-Bands® described in chapter 2. 1.

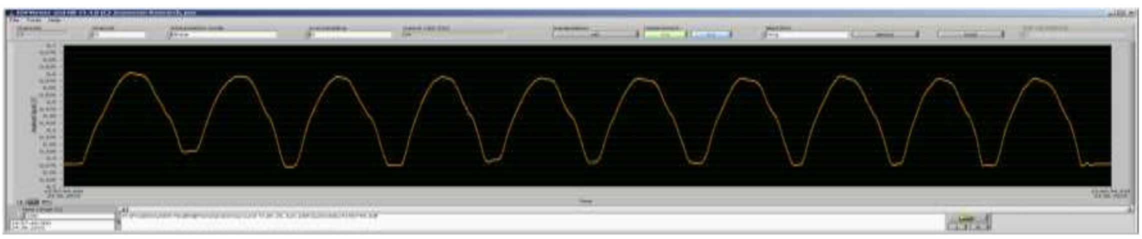

Figure 6: The calculated strength during 10 repetitions of the exercise *heart opener*.

For each Thera-Band® a so-called rating curve could be determined in order to fit best to the physical behavior of the band. During the training the strength could be calculated at 20fps (see *Figure*

6Figure). The average measurement error compared to ground truth data is approximately five percent at a camera distance in the range of 1.5 to 2.5 meters in front of the patient. Higher distances are not recommended because of decreasing accuracy.

4. Discussion

The developed system for visual strength measurement offers a new methodology in the field of home based training. It provides patients a possibility to do monitored weight lifting exercises in their own living rooms. 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. The used stereo camera setup costs about 100 € and therefore the system can be provided at low cost.

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 patients is planned.

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