System for ECG and heart rate monitoring during group training

Antti Vehkaoja, Jarmo Verho, Alper Cömert, Baran Aydogan, Merja Perhonen, Jukka Lekkala, and Jouko Halttunen

Abstract—**We present a system for measuring ECG signals simultaneously from multiple persons during a group training session. The system transmits the signals to a coordinating computer where heart rate and other parameters are calculated from the signals. The heart rate values can then be shown for example through a video projector on a large display along with individual information about the training intensity.**

I. Introduction and Motivation

DIFFERENT group training formats have increased their popularity in recent years. A classical example of group training is all kinds of aerobics classes. In this case, a major reason for popularity is the group spirit and competition, which makes the attendees to push harder while trying to give at least as much effort as the neighboring person. A demand for efficient training in these classes is a skilled and inspiring instructor.

Another kind of group training currently finding its way to the public awareness lies closer to physical rehabilitation. The expansion of cardiovascular diseases in western countries has got doctors thinking of alternative possibilities for drugs and surgical operations in dealing with the problem. It is commonly known and proven in many studies that physical exercise has a tremendous effect on these "standard of living diseases", which besides many cardiovascular diseases also include type 2 diabetes [1,2].

Two major challenges are faced when promoting this alternative treatment. One is how to get the people to exercise. Obviously, while suffering from these diseases they are not used to do much physical exercise. A solution to this is peer group training. When exercising in a group with other people in the same condition, people do not need to be ashamed of their overweight or bad shape. This way the people also get support and encouragement from each other.

Another challenge, especially in group training with cardiovascular patients is how to ensure enough security so that the increased burden for heart caused by training itself would not cause heart problems. Therefore continuous monitoring of heart activity during training and automatic alarming if something goes wrong is needed.

We propose a system that features both of the previously mentioned functions. Our system is enabled to measure ECG signal from several persons simultaneously and calculate a reliable heart rate values. It is also intended to collect information about the functioning of heart and alarm automatically if potential risk is perceived. The current version of our system motivates the trainees by offering training intensity feedback. It shows users their heart rate values and a comparison to the individual target values set by the training program.

II. Related Work

There are currently a large number of projects going on where different technology and services for group training are being investigated. Some products are already commercially available. The two product examples shortly presented here represent systems having totally different target groups.

Suunto Team POD by Suunto Ltd. (Finland) is an example of heart rate measurement system designed for group training. It uses regular heart rate belts having ANT-protocol supporting radios. The receiver unit is connected to a central computer and dedicated software is used to show the heart rates of the trainees. The system supports up to 50 trainees and is especially aimed for aerobics and spinning instructors, team coaches, and physiotherapists. [3]

Drawback of the Suunto Team POD system is that only the heart rate values are sent to computer and therefore only limited amount of conclusions about the operation of heart can be derived. Also the detection of QRS-complex already in the measurement belt and using only one measurement channel disables using more accurate and computationally more intensive detection algorithms, which we are using in our system.

Another commercially available system for simultaneous multiple person monitoring is Quinton Q-Tel RMS. It is intended for cardiac rehabilitation monitoring and easy patient data management. The Q-Tel system has advanced alarm generation functionality and it also includes a pocket assistant for handling exercise parameters while guiding patients on the floor. Depending on the configuration the Q-Tel system is able to handle up to twelve simultaneous measurement devices. [4]

Manuscript received April 7, 2008. This work was supported by CorusFit Inc., a Finnish company providing rehabilitation and group training for CAD patients and people who belong to risk group.

Antti Vehkaoja is with the Department of Automation Science and Engineering, Tampere University of Technology, Tampere, Finland. Phone: +358 40 7393181, e-mail: antti.vehkaoja@tut.fi

Jarmo Verho, Jukka Lekkala, and Jouko Halttunen are also with the Department of Automation Science and Engineering, Tampere University of Technology, Finland.

Alper Cömert and Baran Aydogan are with the Department of Biomedical Engineering, Tampere University of Technology, Finland.

Merja Perhonen is with the CorusFit Inc., merja.perhonen@corusfit.com

The Q-Tel system represents the high end of the multiple persons enabled cardiac monitoring devices and there is an enormous amount of research work behind the signal analysis algorithms and available software extensions.

The measurement system we propose represents something between the two systems introduced here. Its advantage over the Quinton system is that while being more modest it will be affordable choice for large amount of rehabilitation clinics. The main target groups of our system are Coronary Artery Disease (CAD) -rehabilitation patients and other groups that benefit from increased safety against cardiac problems while training.

III. System Architecture

Our measurement system consists of measurement units, network coordinator, and software running on a PC that does the signal processing and visualizes the measurement data. The software for example calculates heart rate values and average QRS complex from the measured ECG signals. Calculated heart rate values can be shown through a video projector on a large screen where the trainees can see their heart rate values and compare them to their own target values given by the training program.

Fig. 1 shows the components of our measurement system.

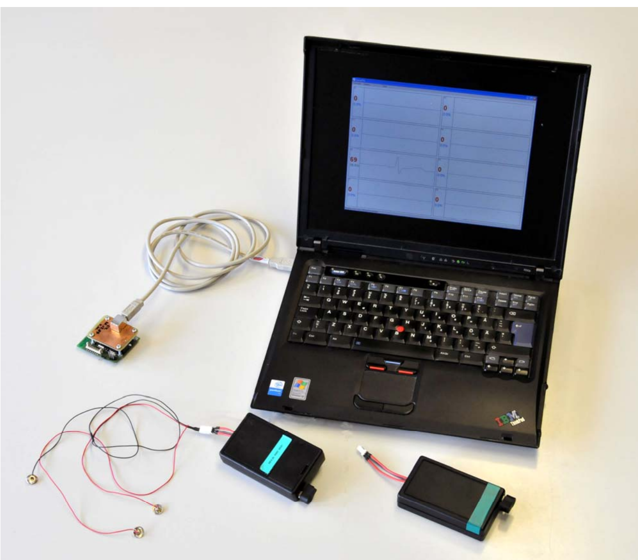

Fig. 1. Measurement system consists of a network coordinator, measurement units, and a PC computer.

A. Wireless Network

We are using a proprietary wireless networking protocol because none of the commonly known standardized protocols suit for our purpose. Standard ZigBee, for example, does not offer enough bandwidth and besides too high power consumption and unnecessarily complex protocol stack, Bluetooth supports only seven slave devices in one piconet.

Our wireless network operates at 2.4 GHz frequency band and utilizes ZigBee compliant radio hardware CC2420 manufactured by Texas Instruments. The protocol is TDMA based, which allows fairly high data throughput. One transmission cycle is divided into ten timeslots. Eight slots are reserved for the measurement devices and two are reserved for retransmissions after possible transmission errors. Network coordinator sends a synchronization beacon in the beginning of every transmission cycle and acknowledges the packet after each received data transmission. The beacon contains addresses of those measurement devices that are allowed to communicate in the network. The coordinator communicates with the PC through a USB bus that is used as a virtual COM-port.

Measurement devices have buffer memory for eight data packets, which equals approximately one second of measurement time. The data buffer is intended to help with the transient packet loss in the cases of a bad link quality. Data is lost if a person goes out of the coordinator's network coverage. Because each measurement device has a dedicated extra time slot for retransmissions in every fourth transmission cycle, each device can operate up to 20 % of average packet loss without losing data.

The transmission coverage of the devices varies depending on the radio interference present and absorption of obstacles, walls etc. Reliable transmit range indoors is usually over 10 meters and even much higher when the radios are in the same space.

B. Measurement Devices

The measurement devices have two channel ECG amplifiers, which are connected so that one common electrode is operating as a reference electrode. The sampling rate in both channels is 250 Hz. The measured ECG signal is sampled with 16-bit resolution, which ensures enough dynamics so that the gain of the amplifier does not need to be adjusted separately for each person being measured. The amplifier circuit has analog filters, which make an initial filtering to 1 - 40 Hz pass band. The total gain of the two stage amplifier is 100.

We have so far used regular disposable ECG electrodes in test measurements with the CAD patients. We have used commercial Blue Sensor R-OO-S electrodes manufactured by Ambu Medicotest (Denmark). The electrodes are placed on the outer brachia of both arms and at the location of precordial lead V4 of the 12-lead ECG system. Latter electrode operates as a common reference electrode.

The trainees are also wearing special measurement vests that are designed to carry the measurement unit and that have embedded channels for electrode leads. We have also tested special textile electrodes in controlled laboratory measurements and they have showed promising results. [5]

Battery life time of the measurement units with AAA-rechargeable batteries is over 70 hours in measurement mode.

C. Signal Processing

The ECG signals received from the measurement units are processed on the PC to extract a few important parameters out of them. The most important parameter when thinking of the training intensity monitoring, is providing reliable heart rate readings. When considering training of people suffering from some cardiovascular disease, the parameters related to the safe operation of heart are also very important. These include monitoring of possible arrhythmia or myocardial ischemia. Arrhythmia is detected as too little and too fast varying R-R interval, whereas myocardial ischemia, which means inadequate blood and oxygen flow into the heart muscle, is detected as a change in the level of ST-segment in the ECG waveform [6].

The key factor in arrhythmia as well as in reliable heart rate and ST-segment detection is as accurate and as flawless recognition of QRS-complexes from the ECG signal as possible. This is an especially difficult task when people are training because of the increased movement and EMG artifact. We are currently implementing algorithms for detecting arrhythmia and myocardial ischemia.

D. *User Interface*

Our current PC software shows the calculated heart rate values and the percentage of the current value from the maximum heart rate of each user, determined in a medical exam, see Fig. 2. This way the trainees can more easily monitor their training intensity and follow their training plan. Heart rate calculation is based on QRS-complex detection. Before the signals are fed to the QRS-detector they are low pass filtered with cut-off frequency of 30 Hz. Heart rate is calculated from an average QRS interval. The QRS complexes shown on a display are also averaged to minimize observed interference.

The update interval of the average QRS-complex and the averaging time are user adjustable parameters. Increasing the update interval increases the required computational power as well as increasing the time of averaging. The default values are 1 s for update interval and 10 s for averaging time.

Fig. 2. User interface of the PC software. Current heart rate value, percentage from the maximum heart rate, and an average QRS-complex are shown for each trainee.

IV. Setup of the Experiment

The system has been tested by CorusFit Inc. [7] in patients with Coronary Artery Disease (CAD) since November 2007. Two test groups have been training twice a week excluding holiday seasons. One test group has five persons and the other has seven. By the beginning of April 2008 there has been altogether 22 training sessions per group with over 250 ECG recordings made so far.

The trainees are executing a mixed aerobic and strength training program. Each training session consists of warm up period, short stretching, aerobical period with a spinning bike, and strength training with lower body muscular training equipment. At the end of a session there is another stretching period. One training session lasts 60 minutes.

Before entering a training group and starting exercising, each person has gone through a full medical exam. Among other things, a maximum stress test with an ergometer has been made to determine the personal maximum heart rate. This is then used to determine the individual heart rate limits for training.

The trainees have been using Polar heart rate monitors [8] as reference devices at a same time with our proposed system.

V. Results

So far the results have been really good; the system has been working well with a couple exceptions in which cases, for an unknown reason, all of the measurement data has not been stored to the PC even though the heart rate computation has been working throughout the training session.

The users of the system have also been satisfied. They have reported that the measurement vests feel comfortable and they are getting the same heart rate readings with both measurement devices.

Fig. 3 shows one minute of recorded ECG signals from all seven persons of the other training group. Signal quality varies during training and also from person to person. Due to motion and EMG artifacts, the quality of the signal measured during training is usually significantly lower that in the measurements made from a person who is not moving. The signals shown in fig. 3 and 4 are raw signals received from the measurement devices and are further digitally low pass filtered in the preprocessing phase at PC.

Fig. 4 shows an enlarged image of ECG signal measured during training. Two main sources of interference are affecting to the signal. One is the movement artifact caused by electrode moving with respect to skin which makes the electrodes' half cell potentials vary and causes an error to the measurement signal. Another major source of interference is the EMG artifact. It originates from the contracting muscles while exercising. EMG artifact exists mainly on higher frequencies than ECG signal and it can therefore be rather easily suppressed by filtering. The source of interference in the example signal is mainly EMG.

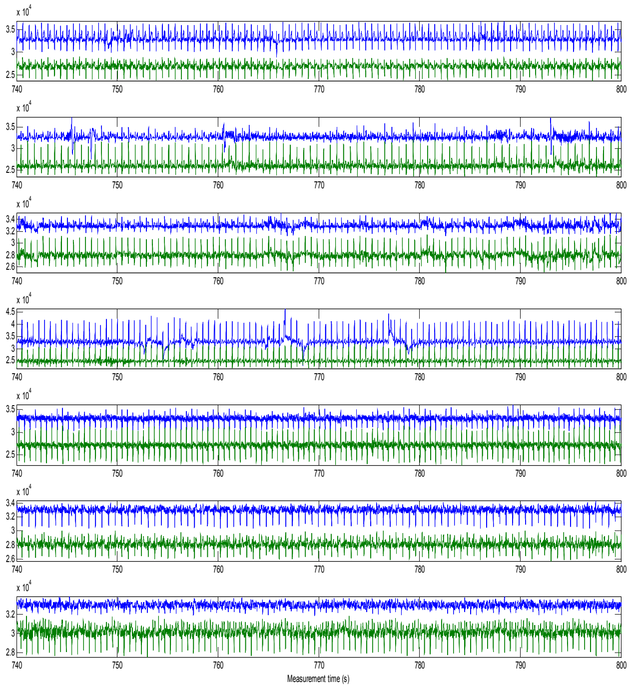

Fig. 3. One minute of ECG data recorded from all seven trainees in the test group at the same time. The signals are recorded in the middle of the exercise period and therefore some artifacts can be seen in them.

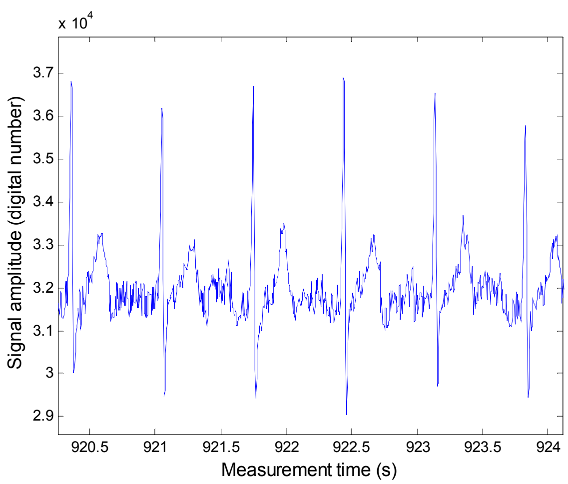

Fig. 4. An example of ECG signal recorded from one of the CAD patients during the exercise. The signal quality is not always this high because of the movement artifact and further filtering of the signal and QRS-complex averaging are needed for reliable detection of desired parameters.

VI. Conclusion

We presented a system that is intended for ECG measurement during a group training session. User experiences so far have been encouraging. Users have reported that the system increases their feeling of security while training because possible changes in functioning of heart can be detected and recognized early enough. It is also easier to keep the training intensity inside the intended limits because the system gives constant feedback to the trainees. We are continuing developing the system and will also create prognosis models about the impact of training using ECG parameters.

VII. Future Work

The presented measurement system is our first prototype and it still needs improvements before it can be commercialized. Besides improving the current device design, connectors etc. we are developing individual heart rate displays by which the users can follow their training intensity referred to the values defined in the training program.

We are planning to include a portable instructor's display into the system as well. With the instructor's display, the training instructor could see the heart rate values of the training group and also receive alarms while giving training instructions and motivating the trainees on the floor.

To further increase the convenience of the measurement system we will start using a new type of textile electrodes instead of the disposable ECG electrodes used so far. We have so far tested different electrode structures and compared the performance of the two electrode types. This evaluation will continue as we start larger pilot tests with the new system. Few pilot tests should be starting within year 2008, one in Singapore and a couple in Finland.

Acknowledgment

We would like to acknowledge Lymed Ltd. (Finland) for providing the measurement vests.

References

[1] Hambrecht, R., *et. al*, (2004) Percutaneous Coronary Angioplasty Compared with Exercise Training in Patients with Stable Coronary Artery Disease. A Randomized Trial, Circulation, Mar. 8 2004

[2] Morton R. Rinder *et. al*, (1999) Effects of Endurance Exercise Training on Left Ventricular Systolic Performance and Ventriculoarterial Coupling in Patients With Coronary Artery Disease, Am Heart J 138(1):169-174, 1999.

[3] Suunto Team POD, Suunto Inc., www.suunto.com

[4] Cardiac Science corporation, Quinton brand, www.quinton.com

[5] Alper Cömert, Markku Honkala, Merja Puurtinen, and Merja Perhonen, (2008) "The Suitability of Silver Yarn Electrodes for Mobile ECG Monitoring", NBC-2008, 14th Nordic-Baltic Conference on Biomedical Engineering and Medical Physics, *accepted*

[6] Rechavia E, *et. al*, (1988) Repetitive ventricular fibrillation preceded by both ST segment depression and elevation during acute myocardial ischemia, Chest. 1988 Jun;93(6):1296-8.

[7] CorusFit Inc., http://www.corusfit.com/index_en.htm

[8] Polar Electro Inc., http://www.polarusa.com