A New System for Integral Community Cardiac Rehabilitation Based on Technological Platforms for the Lifestyle Change Supporting System

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Abstract

The main goal of this work was to design, develop and test a new system for Integral community cardiac rehabilitation phase III (CR-III) based on technological platforms for the LCSS's (Lifestyle Change Supporting System). The system has the following characteristics: personalized cardiac rehabilitation program, automatic support in establishing and modifying care program, risk factor ,monitoring access for the patients, intensive cardiac monitoring with automatic alarms, support self-care programs and continuous information of the therapy results. The LCSS is based on a Control and decision support system (tablet-PC). The system introduces the data for the session on the personal PDA of patient through a Wifi (802.11b) connection. The PDA software works as a personal trainer of the patient, motivating and guiding the patient in his rehabilitation. The biomedical sensors are located on the chest and 6 ECG signals in non-standard leads are recorded during the exercise. Alarm warnings are induced when an ECG frequency higher than the maximal programmed by the system is detected, when an increment or decrement of ST segment is observed and when ectopic activity is detected.

1. Introduction

The Programs of cardiac rehabilitation consist of multifactor therapeutic systems destined to people who suffer Heart diseases. With the practice of prolonged physical exercise and the performance on the factors of cardiovascular risk, it is possible to obtain a slow down in the progression of the arteriosclerosis and decrease of new coronary episodes, as well as the number of hospitalizations and mortality by ischemic cardiopathy, improving the patients well-being [1]. Patients with established CHD are recommended to exercise on an individually adapted level of intensity that accommodates the patients' personal capacity [2].

The main objective of this project is the phase III Cardiac Rehabilitation. This phase must last the patient's whole life, being controlled periodically by multidisciplinary support units (Attending physicians, cardiologists, psychologist, physiotherapists, dieticians, etc.). At Valencia, this activity is carried out by Valencian Heart Institute (INSVACOR).

Recent studies [3] have suggested that participation in cardiac rehabilitation is highly effective in the improvement of patient's LCSS (Lifestyle Change Supporting System). Economic evaluations suggest [4] that CR is a cost-effective intervention, and patients in the home-based arm reported a significantly improved quality of life compared to patients without Cardiac rehabilitation [5].

The aim of this project was to develop and validate a system that will help the specialists to design for each patient the rehabilitation sessions that it allowed to control the sessions of each patient without disturbing its accomplishment and facilitating an evaluation tool for the professionals who treat patients.

2. Methods

The developed system allows the design and control of the heart rehabilitation of different patient. The system consists on a tablet PC managed by the physiotherapist that we will call Control Local Unit (UCL) and different Patient's Unit (UP) that guide and supervise the patient in his rehabilitation. These UP are formed by a pocket PC or mobile device, a system of electrodes on an adjustable vest and amplifier transmitter, forming a personal area network.

From a functional point of view, the system is divided in three phases:

1. *Design and Preparation Phase*. In this phase the UCL proposes a new session of exercises for patients.
2. *Control and measurement Phase* The patient begins the session. Through the system of sensors the ECG signals are transmitted via Bluetooth to the UP that relays the signal via Wi-Fi to the UCL (fig.1). During the session the UP helps the patient in their exercises whereas the UCL is controlling the state of the patients and showing alarms and events occurring during the session.
3. *Managing Information Phase* During and after finalizing the session, the specialist can see information on evolution of the patient. He can also review patient's ECG from the UCL and carry out an evaluation of the rehabilitation for a more effective diagnosis.

The system consists of:

- A Chest Belt with six cardiac derivations.
- Amplifier and Wireless portable Transmitter.
- Software for mobile devices.
- Software for the UCL.
- Establishing an infrastructure of communications for the system.
- DataBase with Patient's information.
- ECG Detection Algorithms.

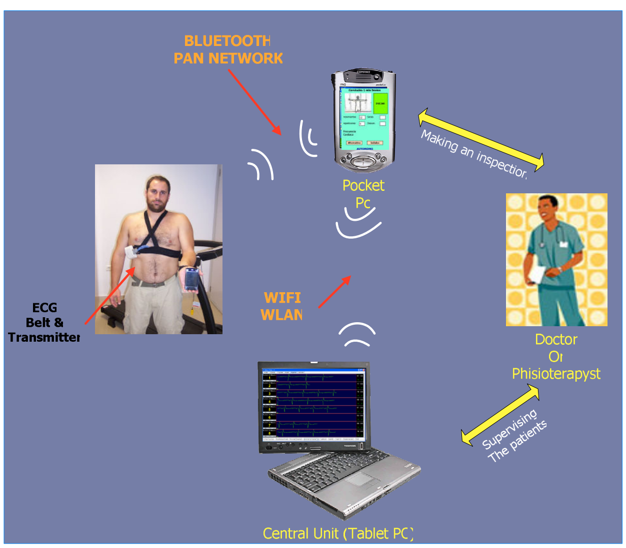

Fig1. General scheme of the system during a rehabilitation session. Two types of networks can be seen : PAN (personal area network) and WLAN (wireless local area network).

2.1. Wearable ECG

For the reception and transmission of the cardiac signals during the physical activity of the patient a special belt has been designed that gathers six cardiac leads assuring a continuous contact during the exercise, without obstructing the mobility of the individual (fig.2). The electrodes are connected to an amplifier of six channels that digitalize the signal with a sample rate of 500 Hertz For communications, a Bluetooth module with the serial port profile and a transfer rate of 115200 bps has been implemented.

2.2. Mobile Device

For the election of UP, Pocket PC device (2003 or windows mobile 5) with Bluetooth & WiFi technologies has been chosen. The application was developed in C# with VISUAL STUDIO .

When the patient begins the session he receives a UP. Then the UP connects with the UCL in a Wireless Network and downloads the personal session calculated by the UCL. From then the patient is guided by the UP through all the exercises observing all the parameters for the exercise (fig.2). While, the UP is able to read the cardiac signals and transmit these signals to the UCL in real time. Besides, the UP can calculate the HRV and ST segment and generate alarms.

The UP uses audio messages to motivate and help people with the cardiac rehabilitation.

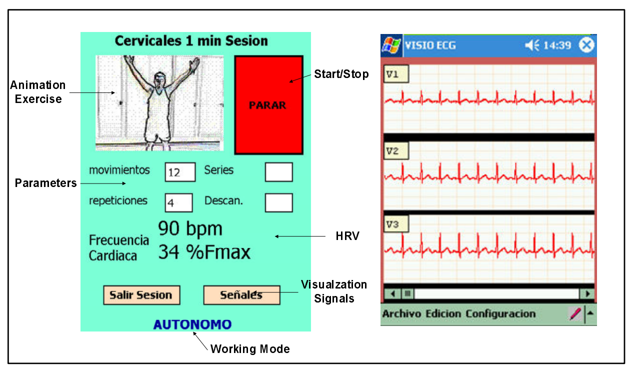

Fig2. Two snapshots of the software for the mobile device. The left image shows how the program guides the patient during exercise and the right image show three derivations of the patient .

2.3. Processing ECG Signal

An ECG detection library for the UP (reduced version) and the UCL has been designed.

The system bases its diagnosis on the analysis of the last 10 seconds of the ECG signal.

Detection of QRS complexes is based on the adaptive threshold algorithm proposed by Pan and Tompkins [6].

With this algorithm, RR intervals and cardiac frequency of the signal are calculated. The signal is filtered to

reduce the presence of artefacts. The detection of morphology of complex QRS was carried out using adaptive thresholds on the real signal and on the derivate of the signal. For the amplitude calculation, the estimation of the baseline was based on an interpolation with cubic splines (fig.3).
The measurement of ST segment is taken 80ms after J point. The signal was filtered using a 30Hz FIR filter. The diagnoses of the signal are taken into account only if there are no Q waves at the derivation.
The detection of ectopic beats is made by studying RR intervals and QRS morphology changes. Besides this, the algorithm detects and warns malfunction of electrodes.

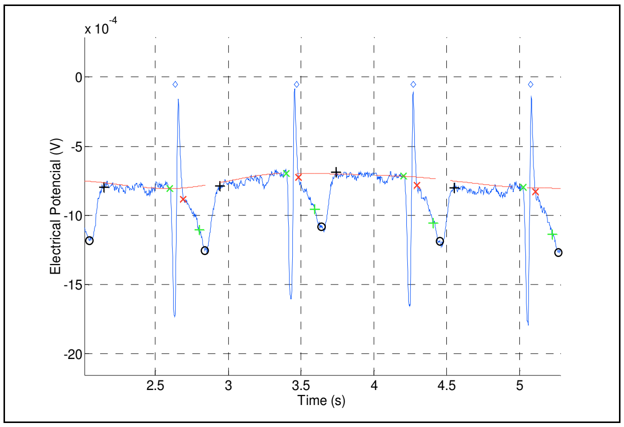

Fig.3. Detection points with our algorithm. Diamond: QRS position, Green Cross: Start QRS, Red Cross: End QRS, Circle: T wave, Green plus: Start T, Black Plus: End T, Red dash line: Base Line

2.4. Local Control Unit. Database

A java application software has been developed for the UCL. The software connects remotely with a PostgreSQL Database that saves all necessary data to design the patients' cardiac rehabilitation. The database is located in an INSVACOR server (UCC). The UCL is the application used by the physiotherapist to control the session. The physiotherapist can download all the patients´ data from the UCC in his UCL. Form the UCC, the specialist may see all the updated data and generate reports, view cardiac registers of the patient and introduce new data to the database.
Once the date are loaded into the UCL, the system automatically designs the next session taking into account the previous sessions , the initial form that the patient fills out and all the important data of the database.
After the patient begins his session, the system shows the cardiac signal of the patient during the exercise (fig.4). When an event occurs (beginning and ending of exercise, emergency stops, alarms) the system shows the information in real time and saves the event and a part of the signal at the memory for its posterior check and .

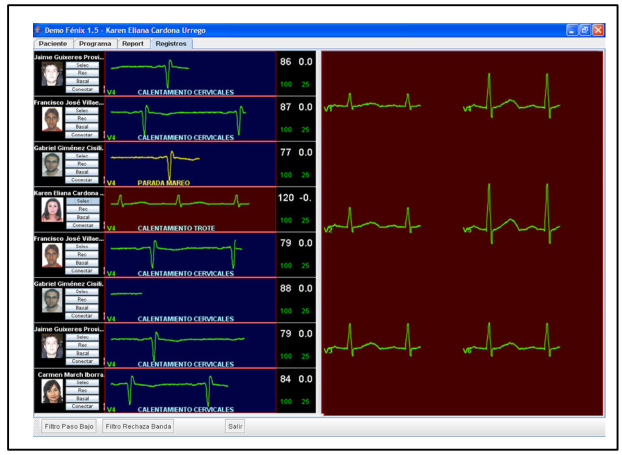

Fig.4. Real time cardiac signals from eight patients during cardiac rehabilitation. The Six derivations of the right side correspond to the selected patient. on the left side.

Each session is designed with a Personal Heart Rate limit. If the limit is exceeded an alarm is sent to the UCL and the UP. Furthermore, there are alarms of ST segment variation, ectopics and electrode malfunction.
We can read the data generated by this session at the reports tab. For developing the application, the code was written in Java using Netbeans
Moreover the application opens and saves SCP-ECG [7] files and calculates European Score Risk Charts [8] taking into account the medical parameters of the patient.

3. Results

Assessment of the system has begun with phase III patients at two gymnasiums where INSVACOR carries out cardiac rehabilitation. The aim of this first assessment has been to validate the functionality of our system.
In order to validate the measurements done by the system it has been used the CTS ECG waves of calibration (UNE-60601-2-51). The test considers correct the waves that differ in less than 50µV if the wave is smaller of 500µV and less than 5% of the wave if it is greater than 500µV. For the QRS duration, deviations smaller than 5ms or 5% of the complex duration are right.
Once the tests are carried out, a coincidence of 100% has been completed among the 200 points of the database and those obtained from our algorithm .
A first group of nine patients without cardiac disease were chosen. Measurements were taken during a circuit with three stages in a treadmill: 2 minutes at rest, 2 minutes at walking speed (3 km/h) and 2 minutes at jogging speed (6 km/h).

Rest	TP	FN	FP	TN
Heart frequency	54	0	0	0
ST Elevation	0	0	0	54
Ectopics beats	0	0	1	53

Walking	TP	FN	FP	TN
Heart frequency	54	0	0	0
ST Elevation	0	0	1	53
Ectopics beats	0	0	1	53

Running	TP	FN	FP	TN
Heart frequency	54	0	0	0
ST Elevation	1	0	1	52
Ectopics beats	0	0	6	48

Total	TP	FN	FP	TN
Heart frequency	162	0	0	0
ST Elevation	1	0	2	160
Ectopics beats	0	0	8	154

Table 1 : Experimental Results

Table1 shows the results produced from different patients in different exercises. The phase with more false positives is the running phase due to motion artefact.

All the wireless links in the Institutional Scientific Medical frequency band (ISM) with communication channels of 11 Mbps throughput at the WiFi connection and 115 kbps at the Bluetooth connection. Due to the data transfer limitation of the Bluetooth connection the UCL doesn't have any problem to receive the signal of the patients. Future improvements of the system should include a method that avoids the loss of information before the communication failures.

4. Discussion and conclusions

In recent years cardiac rehabilitation there has been increased. It confers benefits to the patients and to the professionals' staff. There is a clear need to offer a variety of exercise options for patients including home-based and hospital-base therapy. Besides, the use of the new technologies (wireless, mobile devices, faster processor...) Provide to the patient a safe and easy way to accomplish his exercises and helps the professional to supervise the patient.

The following development phase consists on carrying out a clinical test of the system in patient with heart problems.

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