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A System for Prevention, Care and Rehabilitation of Subject with Cardiovascular Risk: the Signal Processing Algorithm Library

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Abstract— **In the last years the Home Monitoring development is increased both for its capability as a real time tool to manage patients health and to reduce hospitalization costs. The Home Monitoring system is a complex structure that needs the collaboration of different disciplines, from medicine to engineering, and technologies. This project has been developed with the integration of different groups of research as to unify all the necessary knowledge. According to physician exigencies a signal processing library has been implemented to describe in a synthetic and effective way the pathological status of patients with moderate cardiovascular risk. Consequently a software and hardware architecture have been designed to acquire ECG signal, to extract HRV and respiratory information through a multiparametric approach and to store the results. This Home Monitoring system has been projected to work during an appropriate physical training section and its function is both diagnostic and therapeutic as well as for rehabilitation. The aim of this work is to describe the structure of the signal processing library.**

I. Introduction

THE Home Monitoring represents an important way for physician to control the patient health for diagnostic, rehabilitative and therapeutic purposes as to assess the efficacy of treatment. The development of wearable and noninvasive devices and of telecommunication technologies has permitted to improve data acquisition and to obtain more realistic and reliable information of patient conditions than traditional measurements in hospital.

The Home Monitoring is a complex system with updatable knowledge bases from technological and decisional point of view. Indeed it is fundamental not only to acquire and to monitor biomedical signals but also to extract useful parameters to synthesize immediately, in a clear and easy way, the patient health status without excessive information management [1]. Working on this field, it appears of basic importance taking into account signal fluctuations and to organize emergency messages in case of parameters values will out of predefined thresholds or different signal patterns will appear, with minimum transmission delay and without failure [2].

Moreover a great interaction with physician is also recommended to establish how many times, in what representation and to who, the home monitoring information have to be sent.

That is why the system described in this work has been projected by different group of researchers, one for each step (acquisition, signal processing, data transmission and storage, as Figure 1 reports) as to guarantee a precise, reliable and effective tool for the Home Monitoring of patients with moderate cardiovascular risk.

The aim of this work is to explain the signal processing part that has been designed to analyze patients with moderate cardiovascular risk according to a specific training schedule.

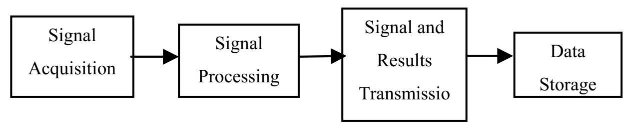

Fig. 1. The Home Monitoring system steps

II. Methods

To describe the health conditions of patients, the ECG signal has been studied during a training program characterized by 30 minutes of cyclette exercise. It has been preceded and followed by 5 minutes rest [3].

ECG signal has been acquired by 2 leads connected to a Microchip DSP micro controller allowing the parallel acquisition and the communication with the "Windows Media Center Server" through either serial cable (RS232) or Bluetooth cableless serial bridge device as to guarantee the data thoroughness and their synchronization.

This board permits to configure the sampling rate (up to 1000 Hz), the exercise duration and the RTC (Real Time Clock) to characterize data file and to set the beginning of the exercise.

All the acquired data have been processed in real time by the "Windows Media Center, WMC, Server" [4,5]: indeed, according to the patient state of moderate cardiovascular risk it has been implemented a signal processing library including algorithms developed in Matlab 7.0 as well as technical and clinical specifications to apply to the ECG analysis.

By using the CSAFE protocol, the cyclette also can be monitored reporting Watt and RPM as exercise parameters to correlate them with the analysis results, thus allowing a feedback to the patient about the performance of the training session.

A WMC platform has been implemented to create local data storage and to guarantee teleassistance service. After a review of telecardiology literature [1] a Central Web Server has been organized and implemented to collect all the data regarding the patient trainings, the results of signal analyses, and cyclo ergometer activities.

Figure2 describes the software signal processing architecture

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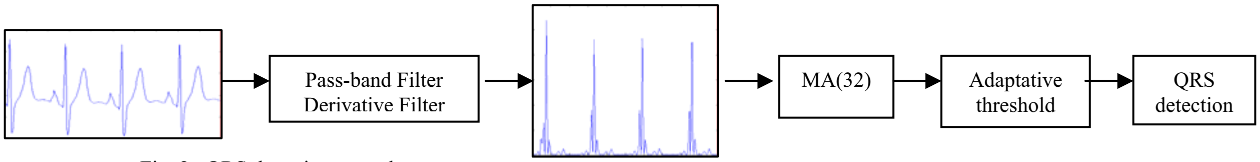

Fig. 2. QRS detection procedure.

which has been defined to extract Heart arte Variability (HRV) signal from ECG in order to discriminate normal vs. pathological behaviour and to describe cardiovascular patterns [8] through a multiparametric approach.

III. SIGNAL PROCESSING

The HRV parameters were extracted according to the Task Force [7]. Beat-to-beat heart rate dynamics and respiratory modulation were computed in real time by “Windows Media Centre”.

Once the ECG signal was stored in a file .csv, the processing sequence extracts RR series, in real time, through the adaptive threshold algorithm by Pan and Tompkins [**].

A. QRS Detection

Pan and Tompkins algorithm has been implemented to recognize QRS complexes (see Figure 2) thus providing the R wave peaks for the RR series computation.

The QRS recognition is based on its morphology only, drawing advantage in particular on combination of its slope and amplitude, which are greater than any other ECG wave.

The “Windows Media Centre” pre-processes the ECG signal by a pass-band filter that selects the ECG frequency bands only as to clear noise components due to muscles electrical activity and environment electrical interferences.

A derivative filter, an absolute value operator and a moving average filter have been implemented to discriminate the ECG segments with the higher amplitude variation referred to 2 consecutive samples time distance. We considered a variable threshold in order to identify QRS complexes without errors which can be caused by patient movements inducing changes in the ECG baseline.

B. Fiducial points recognition

The QRS identification is followed by the recognition of ECG fiducial points, such as R and Q wave peak, through the minimum and maximum signal search in an appropriate temporal window.

Moreover, considering ECG segments without QRS complexes, the T wave and its fiducial points, such as the T wave peak, the beginning and the ending point are also detected.

C. ECG parameters computation

A multiparametric approach applied to RR series has been adopted to completely describe the cardiovascular pattern of the considered patients.

In the same time we have considered and developed an automatic beat-to-beat heart rate dynamic analysis based on Task Force time (statistical and geometrical characterization) and frequency domain parameters which have been proposed to study the HRV signal in different conditions (see Table 1 and Table 2).

D. Respiratory modulation

To extract respiratory information two median filters characterized by 200 msec and 600 msec temporal window widths respectively, have been implemented and applied to ECG signal (see Figure 3).

In particular the first median filter removes QRS complexes and P waves, while the second one is projected to eliminate T waves.

In this way, it has been obtained an ECG signal without the most important waves and complexes whose amplitude oscillations, we can hypothesize, can be due to respiratory movements only.

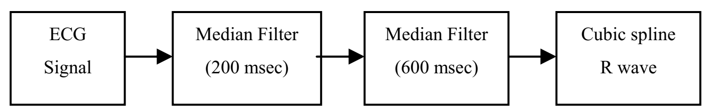

Fig. 3. Procedure extractng the respiratory modulation from ECG.

IV. RESULTS

The signal processing library is implemented to describe completely HRV pattern and respiratory activity during exercise training.

It is possible to clearly discriminate normal and hypertensive patient through a multiparametric approach that permits to evidence alterations in RR-interval dynamics of pathologic subjects.

Subjects presenting great differences in RR length values of nearby beats as it happens in some pathological patient groups, can be studied in an excellent way by Poincaré Plots as to evidence the relation between RR(i) and RR(i-1) (see Figure 4).

The library also includes the computation of the frequency domain parameters since both HRV statistic and geometric measures are influenced more by the low frequency components than by the high ones,

The QRS detection algorithm is reliable during exercise training in spite of heart rate increment and baseline shifts due to patient movements; while the accuracy for the other waves recognition is bounded to the QRS complex one.

Moreover the computation of respiratory modulation component together with the monitoring of the cyclette parameters is an important feedback corcerning the patient health and the exercise training status.

Figure 5 and 6 show some examples of geometrical features and frequency domain parameters estimated in HRV signal obtained from an ECG signal recorded during a 10 minutes training session characterized by 3 minutes of rest (1,5 minutes pre and post exercise) and by 7 minutes of cyclette exercise.

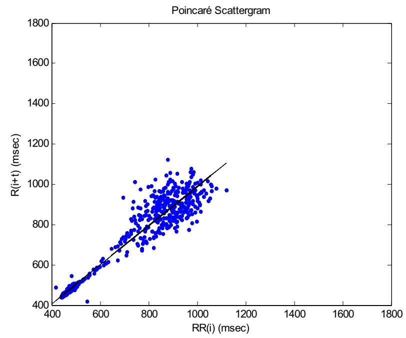

Figure 4. Example of Poincaré plot of a training session of 10 minutes (3 minutes of rest and 7 minutes of cyclette exercise). Data refer to a Normal subject

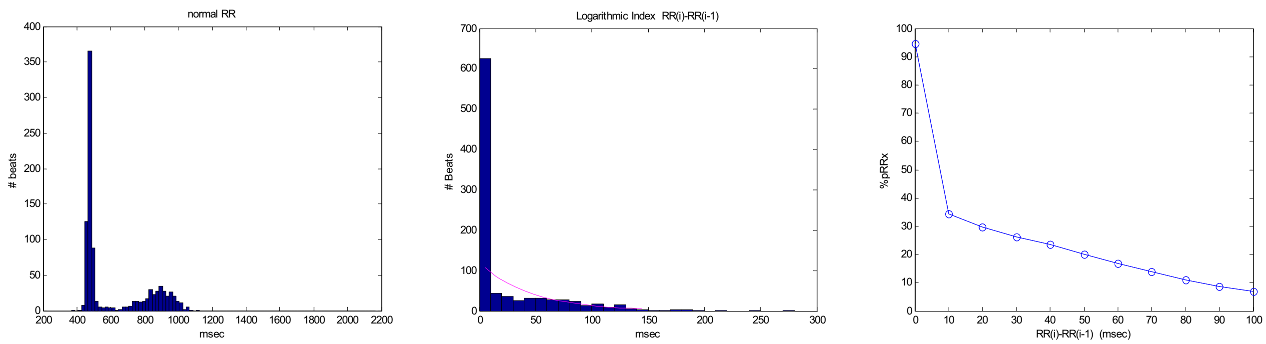

Figure 5. Examples of geometrical features of HRV parameters (RR histogram, logarithmic index of RR differences and %pRRx, that is the percentage number of adjacent RR with a delay absolute value greater than > x msec, from left to right, respectively). Data refer to a training session of 10 minutes (3 minutes Rest and 7 minutes cyclette exercise).

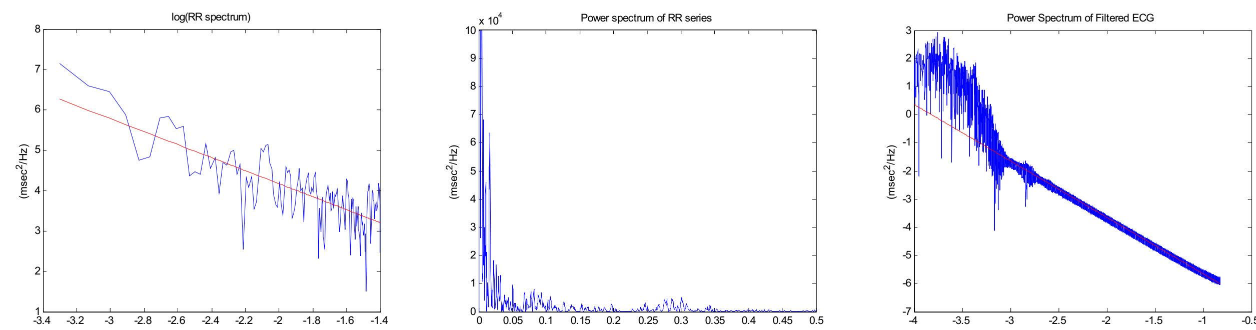

Figure 6. Examples of frequency domain HRV parameters (power spectrum of the RR series in log-log and linear scale, power spectrum of the ECG signal processed with two median filters in log-log scale, from left to right, respectively). Data refer to a training session of 10 minutes (3 minutes Rest and 7 minutes cyclette exercise).

The device portability (only 2 leads) guarantees lack of restrictions of the patient movements without compromising the signal recording.

V DISCUSSION

The paper has illustrated a signal processing library dedicated to Home Monitoring system purposes. Our goal was to construct a knowledge based system providing quantitative knowledge regarding subjects having a moderate cardiovascular risk. Now the system is in a prototype form and it has been evaluated in a set of volunteer subjects in a demo room. In order to obtain a complete library it is fundamental to use it in a clinical research with a large number of subjects in order to compute statistical ranges of normal and abnormal HRV parameters values and to relate them to the correspondent HRV values.

The physician has the possibility both to adapt the exercise training to the single patient and to select the analysis set which is more appropriate to the pathological conditions of the patient.

Moreover to assure the efficacy of the Home Monitoring system it is necessary the cooperation of patient and eventually a feedback of the right position of the devices (electrodes and acquisition board) that have been projected. Another point of interest is concerned with the adaptation of the exercise training to patient pathology.

Finally we intend to improve the system by adding several other functions such as the connection to other medical devices and to extend the application to patients affected by other cardiovascular pathologies.

Table 1: HRV PARAMETERS: **TIME DOMAIN:** STATISTICAL **FEATURES**	
Mean	Mean and standard deviation of all the signal or of its parts
SDNN	
SDANN	Standard deviation of RR means computed every 5 minutes
RMSNND	$\sqrt{\dfrac{\sum_{1}^{N}{}_{k}(RR_k(i)-RR_k(i-1))^2}{N}}$
SDNNi	Mean of RR standard deviations computed every 5 minutes
SDSD	Standard deviation of (RR(i)-RR(i-1))
NN50	The number of adjacent RR with a delay absolute value greater than > 50 msec
pNNX	The percentage number of adjacent RR with a delay absolute value greater than > 50 msec
TIME DOMAIN: GEOMETRICAL FEATURES	
HISTOGRAM	The beats number belonged to RR duration classes (bin)
HTI	The base amplitude (without ectopic beats and artefacts) of RR series histogram
TINN	The triangular base equal to RR density distribution
Φ	Coefficient of $k * e^{-\varphi t}$ that better approximates the $\lvert RR_k(i)-RR_k(i-1)\rvert$ histogram
DI	The amplitude difference of histogram base related to ECG segments with the same length
Ap	Regression slope of Poincaré plot

Table 2: HRV PARAMETERS ***FREQUENCY DOMAIN***	
PLFn	Normalized power (PLF/(PLF+PHF)) in the frequency range [0.04-0.15] Hz
PHFn	Normalized power (PHF/(PLF+PHF)) in the frequency range [0.15-0.4] Hz
AS	Linear interpolation coefficient of power spectrum in the frequency range of]0; 0.02] Hz related to log-log scale
PF	PLF/PHF

VI CONCLUSION

The signal process library we have implemented can represent an important tool to analyze, in a noninvasive way, the cardiovascular behavior of patients with moderate cardiovascular risk.

Moreover the hardware and software architecture allows an accurate analysis which can be chosen by the physician in respect to the single patient needs.

The internet-based platform which is part of our project is pre-arranged not only to manage the home care activities but also to store the patient and the training data as to create a subject database useful to analyze the efficacy of treatments or the pathology degeneration.

What we tried to do is a medical decision-making support for discovering abnormal patterns in ECG recordings and for describing cardiovascular behavior. Furthermore, the described system contributes to attain other two important aspects: the reduction of hospitalization costs and time as well as predictive support for even young patients with moderate cardiovascular diseases.

ACKNOWLEDGMENT

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