HOME MONITORING SYSTEM PROTOTYPE FOR MANAGEMENT OF CARDIOVASCULAR DISEASES

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Abstract: Home monitoring systems aim at treatment of patient care (diagnosis and therapy) reducing hospitalization costs. A software and hardware architecture has been designed to acquire ECG signals, to process them and to archive results. We propose a multi parametric approach based on time and frequency domain and on complexity parameters to analyze patient cardiovascular trend during a physical training section. Collection of an inter and intra subject database will be the base to discriminate pathological and physiological behavior and to enable patient treatment. The prototype we propose integrates different technologies (data acquisition, processing, on line transmission and web-based data storage) to face clinical aspects (prevention, diagnosis, therapy, admission, home assistance). In this way this out-of-hospital system permits not only data visualization and collection in real time but also a closer relationship between patient and physician.

Introduction

Telemedicine represents an opportunity to follow in real-time, at distance, subject conditions through the use of medical knowledge and telecommunication devices support [1].

Home monitoring is assuming more and more importance to perform patient diagnosis and therapy and to reduce hospitalization costs [2]. Telemedicine technologies allow unifying different clinical objectives: prevention, diagnosis, therapy, admission, home assistance, as to produce a “knowledge managed care” model [3].

The objective of our project is not only to check patient healthy conditions but also to revise care efficacy as to eventually modify pharmacological treatments. This out-of-hospital system makes closer patient-physician relationship because of patient active participation to his/her own treatment process.

The introduction of telemedicine technologies permitted to unify different clinical objectives .In this way prevention, diagnosis, therapy, recovering, home assistance constitute as to realize a “managed care” model [4]. In this way it is possible not only to check patients health condition but also to study care efficacy as to eventually modify pharmacological treatments.

Materials and Methods

Population

To test the hardware and software platform 24 subjects have been selected and their ECG signal has been analyzed. In particular these subjects have been divided in two classes: normal (14 subjects, mean±SD, 54±11.5 years) and hypertensive (10 subjects, 40.7±1.0 years) ones. It has been considered as normal all the subjects whose clinical cardiologic work-up has been considered negative without the assumption of any anti arrhythmic drug.

Exercise protocol

We defined an exercise protocol for the treatment of patient characterized by a moderate cardiovascular risk.. In order to monitor the subject conditions and to follow the care evolution, a 30 minutes bicycle training protocol was designed. 10 minutes ECG signal before and after the exercise were not considered. A 3-lead standard ECG acquisition took place during patient exercise around 5 p.m. by a dedicated stand-alone prototype board, which has been developed in our labs (see Figure 1).

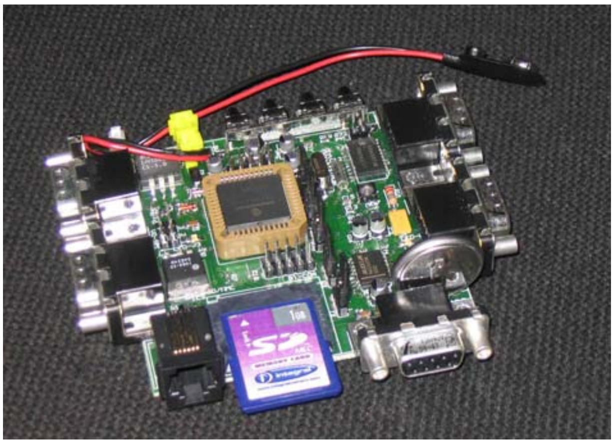

Figure 1: Prototype layout (8cm x 10cm).

Hardware architecture and firmware

The core of the acquisition board used to collect data is a Microchip PIC18F458 micro controller. It was chosen due to its low cost and its several peripheral functions.

To interface the board with a wide number of devices, four analog and four digital inputs were provided, as shown in Figure 2.
The micro controller can store data either into a memory stick storage device or remotely into a "Windows Media Center Server" where data will be later processed.
The communication with the server is guaranteed by either serial cable or Bluetooth cableless serial bridge device, which can be connected directly to the board.
A real time clock (RTC) was also included to allow the board either to characterize data file or to advise the patient to start the acquisition session.

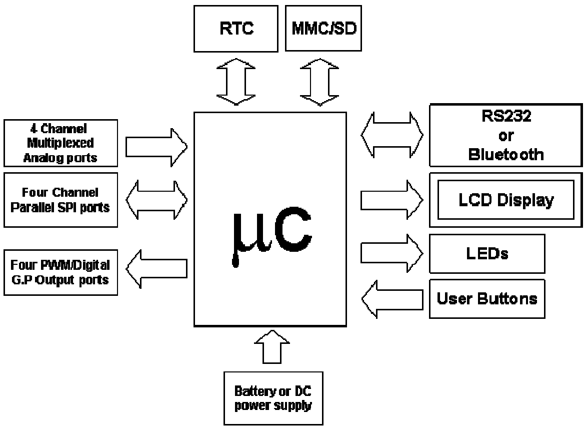

Figure 2: Functional block diagram

The firmware was developed in order to optimize the sampling rate up to 1200 samples per second during the acquisition while, in stand-by mode, it allows the system configuration via serial protocol. Otherwise the configuration can be done directly on board by an intuitive menu if an optional liquid crystal display (LCD) is also available.
Several parameters like the sampling rate, the RTC and the exercise duration are configurable.
The use of LCD can also be used to give a feedback to the patient about the performance of the training session during and after the execution.
To allow an easier data exchange with Matlab, ECG files are stored into the SD/MMC as ASCII format.

Software architecture

Once stored in a file .txt, all the ECG signal was submitted to s processing by the "Windows Media Center" through a multiparametric real-time approach. Algorithms were developed in Matlab 7.0. The objective of the analysis by advanced signal processing tools is to discriminate normal and pathological behavior and to describe patient cardiovascular patterns. The calculated indexes include the Task Force clinical heart rate variability (HRV) parameters [1]. In this way, we extracted the beat-to-beat heart rate dynamics information, which was subsequently sent s to physician [5].

ECG signal processing

In order to recognize fiducial points such as Q and R wave peaks, we have analyzed the 1st-lead standard ECG.

The first step extracting and representing the knowledge, from the ECG signal was to extract the RR interval series, which is the core of a quantitative HRV analysis. Usually, R wave peak is used as the reference point because of its detection is quite simple.. We created a processing library implementing classical and advanced methods to analyze HRV signal and extracting breath modulation, which is an useful indicator in the detection of arrhythmic events..

Detection of fisucial points in the ECG signal

QRS detection

The ECG analysis is based on the QRS recognition and the associated identification of other waves through the adaptive threshold algorithm of Pan and Tompkins. When it was transmitted to the "Windows Media Center", the ECG input signal has been pre-processed through a pass-band filter as to remove other signal contributions that do not characterize standard ECG frequency information. In this way it has been possible to study ECG signal as to detect and recognize QRS complexes.. This step took advantage of the QRS morphology, which is characterized by slope and amplitude values greater than any other ECG wave. A derivative filter has been applied together with an absolute value operator in order to enhance the amplitude difference referred to 2 consecutive samples. Finally, the Moving Average MA(32) filter has been implemented as to cancel all those artifacts superimposed to the ECG frequency information. Using an adaptive threshold it has been possible to detect QRS complexes and consequently their duration even when ECG amplitude shifted due to patient movements.

R and Q wave peaks detection

Once the QRS complexes were located in the ECG segments fiducial points were detected by searching minimum and maximum point value respectively, in an appropriate time windows. R wave peak has been found as the absolute maximum value in the ECG segment characterized by the presence of the QRS wave; Q wave peak has been detected as the minimum point in an ECG time window placed 200 msec before R wave peak detection.

ECG parameters estimation

RR series have been constructed by measuring the peak-to-peak distance between R waves. These series have been processed automatically to obtain, through a multiparametric approach, beat-to-beat heart rate measures and HRV analysis based on Task Force time (statistical and geometrical characterization) and frequency domain parameters. Tachogram and RR duration histogram have been computed, thus generating RR classes whose duration depends on sample frequency (2/fs [msec]). As concerned statistical

HRV evaluation, we calculated: SDNN (RR intervals standard deviation), CoV (variation coefficient; it is equal to 100*SDNN/MeanRR) SDANN (average RR intervals standard deviation, calculated over 5 min ECG intervals), RMSSD (the root mean square of the sum of the squares of differences between nearby RR intervals), p50NN (percentage of differences between adjacent normal RR intervals exceeding 50 msec). Among geometric indexes we measured: the HRV triangular index (the integral of the density distribution divided by the maximum of the density distribution), TINN (the baseline width of the RR interval histogram triangular interpolation), the differential index (the difference between the width of the histogram of differences between adjacent RR intervals measured at the level of 1000 and 10000 samples), the logarithmic index (the coefficient φ of the negative exponential curve $ke^{-\varphi t}$, approximation of the histogram of absolute differences between adjacent RR intervals).

Frequency domain non-parametric techniques (based on DFT approach and FFT algorithm) have been calculated: total power (0.01 to 0.40 Hz), high frequency power (HF, 0.15 to 0.40 Hz), low frequency power (LF, 0.04 to 0.15 Hz), very low frequency power (VLF, 0.01 to 0.04 Hz), and LF/HF ratio. LF and HF were further normalized (PLFn and PHFn) to better quantify autonomic balance. The α-slope index, measuring the spectrum slope in log-log scale, in the frequency range of [0.0001:0.02] Hz, has been also measured.

Breath modulation processing

Once obtained RR series together with R and Q waves peaks position, it has been a consequence to calculate breath modulation as a cubic spline interpolation of both R wave and Q wave peaks (see Figure 3). That was the way to estimate a breath signal directly from the ECG signal, on a beat-to-beat basis.. This use the R wave peak as the fiducial point to study breath modulation implies that breath movements have caused all the R wave amplitude variations. For this analysis it was necessary to compare the amplitude and time characterization of the R wave peaks with the Q wave recognition as to discriminate artifacts owing to movements. Indeed all the two waves have been conditioned in the same way by movement artifacts as well as by breathing activity. In particular the waves amplitude variations have to be the same for movement artifacts without affecting morphology and waves interval. The cubic spline interpolations of R and Q wave peaks have then been processed through fast Fourier analysis using the Bartlett window to obtain the spectral power.

Graphical visualization

A graphical interface has been developed to make easier and faster physician interpretation and eventually to visualize ECG intervals characterized by clinical interest as to permit sending to physician and to patient.by mail or by SMS a short evaluation of the exam.

Data and output storage

The “Windows Media Center” was not only a signal processing station but also a local data repository. A retrospective evaluation of the exam results takes place in the central repository which is located in the central web server.

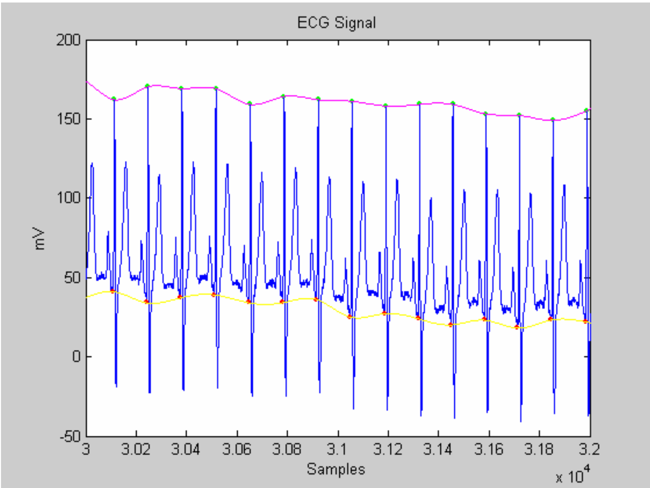

Figure 3: R (green points) and Q (red points) wave peaks detection and fiduciary points cubic spline interpolation to analyze breath modulation (ECG sample frequency equal to 200 Hz).

Results

This prototype permits a complete description as concerned HRV pattern of patient during exercise training (see Table 1). For example it is possible to discriminate normal and hypertensive patient through Poincaré plot (see Figure 4) in which alterations in RR-interval dynamics are evident. ECG analysis has been useful to underline the electrical instability of hypertensive subject presenting greater differences in RR lengths of nearby beats (see Figure 5). Both HRV statistic and geometric measures evidenced more important influence of the low than of the high frequency components.

The QRS detection algorithm demonstrated its reliability in sudden changes of both heart rate and ECG baseline owing to patient movements; the R peak has been correctly located indeed with a ±1 sample accuracy. It is important to notice that the beat-to-beat QR time interval is characterized by a quite constant value with only one-sample differences due to Q wave detection accuracy. This result confirms that this interval was not influenced by the heart rate value (see Figure 6). Moreover the amplitude between Q and R wave peaks is limited within a precise range of values (see Figure 7).

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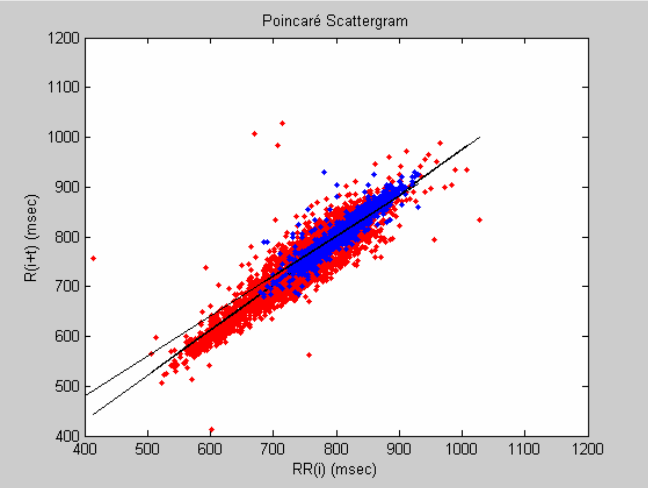

Figure 4: First-order difference plots (Poincaré plot) derived from the RR intervals obtained from a healthy (blu points) and hypertensive (red points) subject.

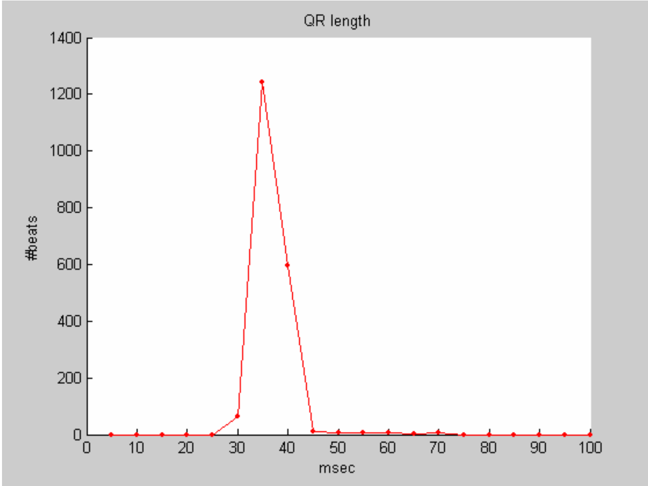

Figure 6: Beats number as the RT length function belonged to normal subject (ECG sample frequency equal to 200 Hz).

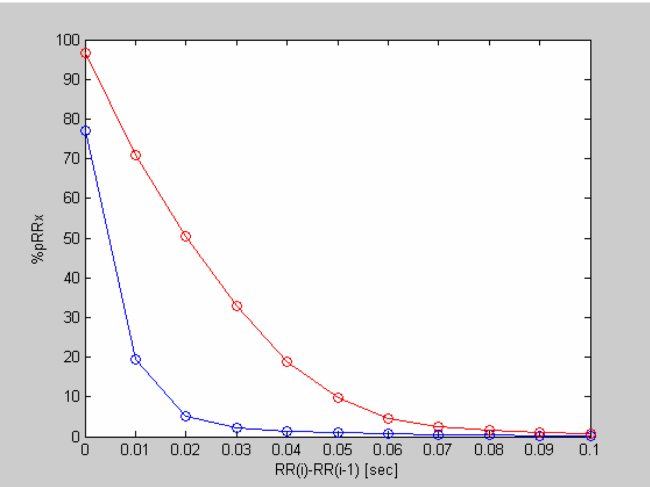

Figure 5: First-order difference plots (Poincaré plot) obtained from a healthy (blu points) and hypertensive (red points) subject.

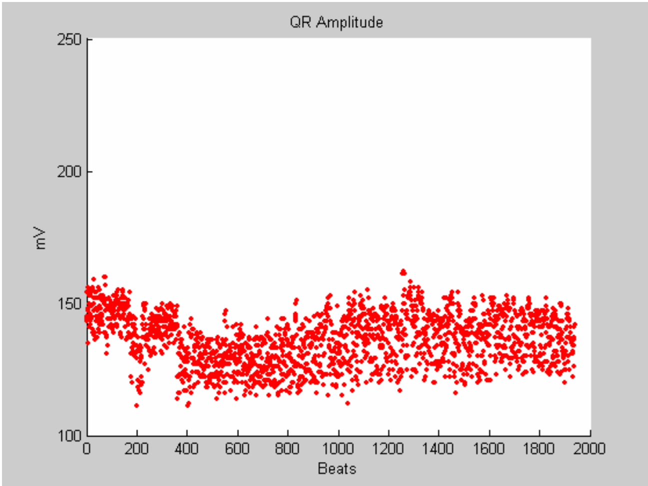

Figure 7: QR amplitudes belonged to normal subject.

Table 1: Time and frequency domain parameters values calculated for a normal and for a hypertensive subject.

HRV	**NORMAL SUBJECT**		
Time Domain	**Statistical Proprieties**		**Geometrical Proprieties**
Mean	621.39msec	HTI	11.34 msec
SDNN	39.84msec	Differential Index	
CoV	6.41	TINN	770msec
SDANN	34.24msec		
RMSNND	989.84msec	**Frequency Domain**	
SDSD	18.40 msec	PLFn	73.65%
pNN50	0.5%	PHFn	26.35%
		PF	2.79

HRV	**HYPERTENSIVE SUBJECT**		
Time Domain	**Statistical Proprieties**		**Geometrical Proprieties**
Mean	525.21msec	HTI	10.71msec
SDNN	63.05msec	Differential Index	
CoV	12	TINN	480msec
SDANN	54.85msec		
RMSNND	2535.2msec	**Frequency Domain**	
SDSD	43.30msec	PLFn	43.86%
pNN50	1.7%	PHFn	56.14%
		PF	0.78

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R wave amplitude changes looked amplified as the bigger slope of the absolute value. In fact, each maximum amplitude change of the Q wave founded a correspondence in a larger change of the R wave maximum amplitude. In this way it is possible to compare the cubic interpolations of R and Q wave peaks as to obtain a more reliable breath modulation.

Discussion

To realize HRV analysis the Task Force clinical parameters have been calculated. This multiparametric approach has been useful to extract information about heart rate variability non invasively and automatically. The proposed parameters are markers of sympathetic and parasympathetic influences on the modulations of heart rate, and of the beat-to-beat heart rate dynamics as to recognize pathological and physiological cardiovascular conditions [6-8]. Poincaré plot evidencing clear changes of successive RR intervals could be an example of what these techniques could do.. Moreover statistical RR variability analyses have underlined physiological and pathological cases, in particular SDNN, pNN50 and RMSNND mainly have reflected the parasympathetic system influence. Even if frequency components are important to study sympathetic and vagal activation, the hypothesis of RR stationarity represents a limit. Very low frequency components were not considered because of the too short ECG length does not allow their analysis.. Moreover frequency-domain HRV parameters are less stable than time-domain ones, especially when short-term ECG recordings are considered. Widening the number of experimental subjects could facilitate the construction of a library characterized by significant parameters and clinical documentation as to describe parameters features with normal/pathological ranges, input specificity (i.e., minimum sample rate), output characteristics related to specific population classes (for example factors, such as age and gender, influence HRV pattern) and as to give a reliable knowledge representation. The parameters range characterization permits the association of an alarm warning with out-of-normality range parameters cases. Furthermore, the remote archiving allows feedback controls as to influence patient exercise program due to a specific rehabilitation treatment.

Conclusion

The proposed prototype utility has been projected not only to transmit signals but also to summarize recording clinical aspects hidden in ECG signal in a simple and effective way allowing a retrospective analysis to establish or change care treatments. The “Home Tele-care and Tele-Rehabilitation” prototype flexibility and usability permit both to manage different diseases, to guarantee an active intervention at all disease stages and to study care treatment evolution as well as other training protocols.

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