A Knowledge Based Home Monitoring System for Management and Rehabilitation of Cardiovascular Patients

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Abstract

A "managed care" model (prevention, diagnosis, therapy, admission, home assistance) has been realized to permit both a continuous patients check without hospitalization and a patients data archiving. An hardware and software architecture has been designed to manage the out-of-hospital treatments of patients with a moderate cardiovascular risk; as all the sensors built are wearable the cardio respiratory recording may have place during patients exercise program. Transmitted by wireless ECG has been automatically processed by "Windows Media Center" through a multi parametric approach based on time and frequency (linear and non linear analysis) domain study. Advanced characteristics have been utilized by this monitoring prototype and different technologies, such as data acquisition, elaboration, on line transmission and web-based data storage, have been integrated for knowledge management; in this way it is possible not only data real time visualization and collection but also a continuous patients management useful to improve life quality.

1. Introduction

To reduce both time and hospitalization costs has become an exigency more and more relevant and telemedicine plays a significant role to satisfy it providing clinical information and health management at distance guarantying assistance [1]. In this implemented telehealthcare prototype, it has been focused on the transfer of basic biomedical signals and clinical information by wireless connection system to different networks as to permit patient monitoring, diagnosis, treatment, therapy and remotely consulting [2-3]. It becomes fundamental the patient education to use systems that allow access to telecommunication and technology devices. The devices and software effectiveness is guaranteed by the technology integration with healthcare applications, clinical processes and protocols. Moreover, it is required a proper infrastructure, such as acquisition and telecommunication devices, computer systems and data archiving. This information management permits both to manage disease and to monitor physiological behavior by the prototype flexibility [4].

2. Methods

2.1. Population and material

The considered population includes 14 subjects (mean±SD, 54.0 ± 11.5 years), diagnosed as normal on the basis of a clinical cardiologic work-up and not assuming any anti-arrythmic drug. 10 hypertensive patients (40.7 ± 1.0 years), have been also analyzed. A 30 minutes bicycle training protocol was designed to study subject health and care evolution, not considering 10 minutes ECG signal pre and post exercise. During patient exercise that took place approximately at 5 p.m. a 3-lead ECG device output was acquired by a dedicated stand alone prototype board developed in our labs (see Figure 1).

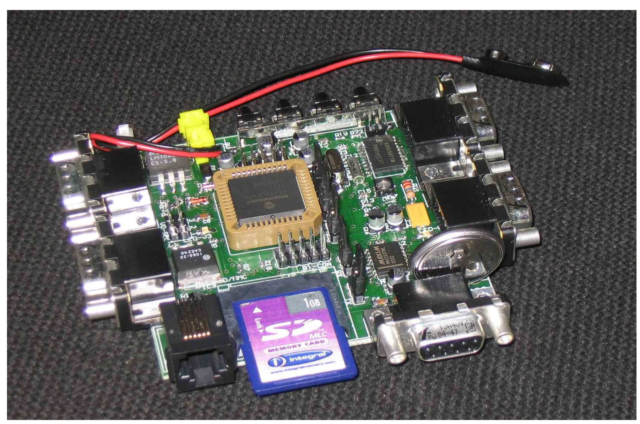

Figure 1. The prototype layout (8cm x 10cm)

2.2. Data acquisition

The core of the acquisition board used to collect data is a Microchip PIC18F458 microcontroller. It was chosen due to its low cost and its several peripheral functions. The microcontroller can store data either into a memory stick storage device or remotely into a “Windows Media Center Server” where data will be later processed. Either serial cable or Bluetooth cable less serial bridge device, which can be connected directly to the board, guarantees the communication with the server.

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. To allow an easier data exchange with Matlab®, ECG files are stored into the SD/MMC as ASCII format.

2.3. ECG signal processing

The algorithms developed in Matlab® have been designed to analyze an ECG signal of 30 min length. As a first step, the acquisition from a standard lead was stored in a text file format as to extract relevant clinical parameters. They are useful to discriminate normal and pathological behavior and to describe patient cardiovascular pattern [5]. It has been applied a multiparametric approach to extract information about HRV, a marker of sympathetic and parasympathetic influences on the modulations of heart rate, and beat-to-beat heart rate dynamics.

Detection of fiducial points in ECG

The adaptative threshold algorithm proposed by Pan and Tompkins has been used to obtain RR series through The recognition of the QRS complexes. The QRS detection takes advantage of the complex wave morphology, that is its greater slope and amplitude. A band-pass filter has been applied; followed by a derivative one. Finally, the square values of filtering results were submitted to a Moving Average procedure MA(32). An adaptative threshold for QRS detection has been chosen as to follow ECG baseline changes due to patient training movements. In this way, it has been possible to obtain RR series considering the R-wave peak as the maximum point of the QRS complex. Then the Q peak- has been detected as the minimum point of 100 msec temporal window before the R wave; finally it has been computed a cubic spline interpolation of both R and Q peak-waves as to study respiratory artifacts (see figure 2).

ECG parameters estimation

RR tachogram and RR duration histogram with amplitude of bin function of ECG sample frequency (2/fs [msec]) have been computed. Once obtained RR intervals series, this knowledge based system permits to process automatically HRV on time (both statistical and geometrical Task Force parameters) and frequency domain (short period parameters) by a multiparametric approach. For example, as concerned statistical HRV assessments, it has been obtained: SDNN (RR intervals standard deviation), SDANN (average RR intervals standard deviation, calculated over 5 min ECG lengths), RMSSD (the root mean square of the sum of the squares of differences between adjacent RR intervals), p50NN (percentage of differences between adjacent normal RR intervals exceeding 50 msec). Frequency domain techniques 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 (0.01 to 0.04 Hz), and LF/HF ratio.

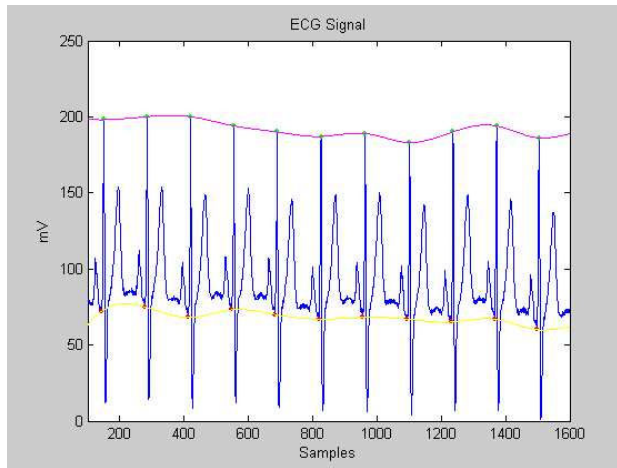

Figure 2 ECG signal processing (200 Hz sample frequency). R and Q wave peaks detection and cubic spline interpolation of ECG fiduciary points.

2.4. ECG process transmission and storage

Once the clinical parameter ranges were defined and all processing results were stored in an Excel file. a message is sent to the physician, the patient and eventually, to an emergency centre. To facilitate a remote consulting it is necessary to optimize the dimension of the stored data. The system has been projected to store both 30-min ECG in a text file and clinical parameters in Excel file format.

3. Results

The knowledge-based system realizes a complete and automatic description as concerned HRV pattern of patient during exercise training. In figure 3, RR interval histograms of a normal subject and of an hypertensive one are shown: in this case it is possible to appreciate a greater RR dispersion as concerned pathological subjects [6]. The cardiovascular behavior has been also discriminated by calculating the Poincaré plot (see figure 4) in which alterations in RR-interval dynamics are evident for pathological subjects.

The ECG analysis of hypertensive subjects has been useful to underline their electrical instability showing greater differences of the adjacent RR lengths. Table 1 shows mean and std values of HRV parameters calculated in a subgroup of normal (N=14) and hypertensive (N=10) subjects. All considered subjects have been selected to test the system prototype so and they do not constitute at the moment a homogenous population but some sample cases only.

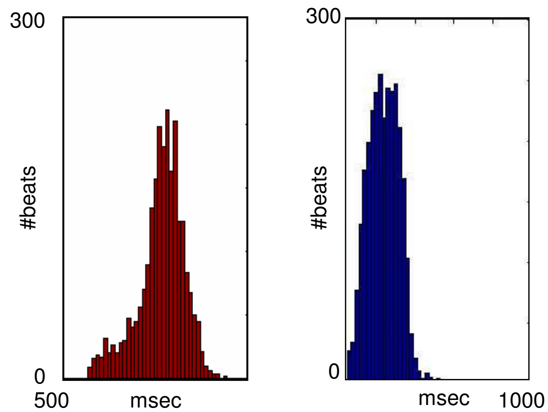

Figure 3. Example of the histogram of the 30min RR serie belonged to an hypertensive subject and to a normal one is computed

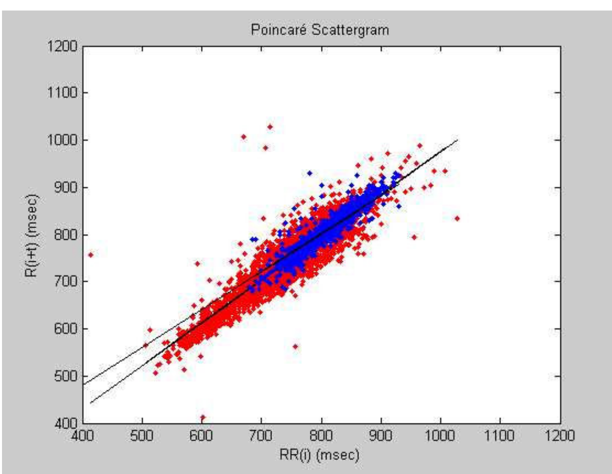

Figure 4: Poincaré plot derived from the RR intervals obtained from a healthy (blue points) and hypertensive (red points) subject.

4. Discussion

The QRS detection algorithm efficacy has been relevant in the case of sudden changes of both heart rate and ECG baseline owing to patient movements. This "managed care" system reveals in a qualitative and quantitative way the subjects cardiovascular behavior and it describes any possible abnormal HRV parameters value and beat-to-beat heart-rate dynamic, due to pathological and physiological cardiovascular conditions [7-8]. By a linear and non-linear analysis, it has been possible to investigate in a non-invasive and automatic way cardiac autonomic functions [9]. For example, statistical parameters, such as SDNN, pNN50 and RMSNND, reflect the parasympathetic system influence.

As a matter of fact, data in Table 1 show large variability and high std values confirming that this preliminary dataset does not allow a reliable patient classification.

It is necessary to increase the number of experimental subjects as to facilitate the construction of a library characterized by significant parameters and by their features, such as normal/pathological ranges, clinical documentation and input specificity (i.e., the minimum required sample rate).

Output characteristics related to specific population classes (factors, such as age and gender, both influence HRV pattern) could be extracted.

This library represents a way to give a reliable knowledge representation. An alarm warning could be activated in case of out-of-normality range parameters. Furthermore, the remote archiving allows feedback controls as to influence patient exercise program due to a specific rehabilitation treatment.

5. Conclusion

The projected prototype shows its usefulness not only to transmit biomedical signals but also the results of their processing procedure as to summarize clinical aspects of the monitoring session and to permit a retrospective analysis in order to set up or change care treatments. Moreover wireless recording permits patient monitoring in a more comfortable way staying at home. Furthermore, this tele-healthcare prototype implies interactive relationship patient-physician.

The knowledge base structure of the ECG processing modulus allows configuring the system for almost each subject/patient. The calculation of set of quantitative parameters strongly helps the correlation of pathological patient states to changes that are observed in index values. What many research works in the recent literature have confirmed, could be fruitfully applied to prevent cardiovascular risk conditions.

For its flexibility and usability this "Home Tele-care and Tele-Rehabilitation" prototype can be applied both to manage different diseases, to guarantee an active intervention at all disease stages and to study care treatment evolution and other training protocols.

Table 1. Time and Frequency Domain Parameters of Normal (up) and Hypertensive (down) subjects

HRV PARAMETERS OF NORMAL SUBJECTS (N=14)			
Time Domain	**Statistical Proprieties**		**Geometrical Proprieties**
Mean [msec]	772.7±132.1	HTI [msec]	9.8±2.5
SDNN [msec]	47.6±11.5	TINN [msec]	286.4±201.8
RMSNND [msec]	1237.1±400.8	**Frequency Domain**	
SDSD [msec]	25.8±10.0 1000	PLFn 500	0.44±0.14
pNN50	0.014±0.020	PHFn	0.55±0.14
		PF	0.99±0.81

HRV PARAMETERS OF HYPERTENSIVE SUBJECTS (N=10)			
Time Domain	**Statistical Properties**	**Geometric Properties**	
Mean [msec]	718.6±87.2	HTI [msec]	9.6±3.0
SDNN [msec]	53.1±15.6	TINN [msec]	283.5±169.2
RMSNND [msec]	1397.4±599.2	**Frequency Domain**	
SDSD [msec]	34.9±10.6	PLFn	0.47±0.11
pNN50	0.037±0.037	PHFn	0.52±0.11
		PF	1.03±0.54

Acknowledgements

This work has been made as a part of the MIUR FIRB project 2003-2006: "Information and communication technology for the management of prevention, care and rehabilitation processes" - Italian Ministry of Research and University.

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