Heart Rate Variability (HRV) Analysis Using DSP For The Detection Of Myocardial Infarction

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***Abstract*— Spectral analysis of heart rate fluctuations are commonly used as quantitative and non-invasive techniques for the study of short-term cardiovascular control functions. Such fluctuations contain key information relating to sympathetic and parasympathetic activity within the cardiovascular control system. This employs ECG complexes to determine the R-wave occurrences and IBI interval lengths. It has been shown that the variations in the interbeat interval time series show key frequency-specific properties.**

This work demonstrates high precision algorithms (Matlab and MikroC algorithms) and a state of the art "interpolation process", to accurately detect R-points and translate them into uniformly sampled signals. Power Spectrum analysis of HRV signals has shown distinct differences between MI patients versus normal subjects. This provides the opportunity to quantify ANS imbalances, leading to distinct classification of Myocardial infracted patients from normal subjects. For real time implementation, a dsPIC microcontroller was programmed using the "MikroC" software.

Keywords— ***ECG, QRS detection, Heart Rate Variability, Interpolation, power spectrum, dsPIC.***

I. INTRODUCTION

The heart is composed of muscle tissue that contracts and relaxes in a coordinated manner when an electrical stimulus is fired. The function of the heart is to pump blood throughout the body, via the arterial system to enable the transport of vital nutrients and oxygen. The heart receives its oxygen and nutrients from arteries, which are the coronary arteries in this case. A blockage of these vessels often leads to a heart attack (the cessation of the beating of the heart). In fact, coronary heart diseases have shown to be the leading cause of death worldwide.

Cardiovascular heart diseases, such as *Myocardial Infarction,* is the number one leading cause of death in different countries around the world. Having the ability to detect the symptoms and the ability to detect the onset of myocardial infarction can greatly decrease the mortality and morbidity of patients.

ECG is a nearly periodic signal that reflects the electrical activity of the heart. A lot of information on the pathology and normal function of heart can be obtained from ECG. However, being dynamic in nature, it is very difficult to visually analyze these ECG traces. Thus a computer based method is required for ECG signal analysis.

Almost fifty years ago*, Schneider and Costiloe* reported that the heart rate in human beings, which is measured by beat-to-beat intervals, is not constant and varies over time. This observation led to a field of studies that investigated heart rate variability (HRV) in several diseases, including coronary artery disease and myocardial infarction (MI). **[9]**

Heart rate (HR), like many physiological set points, e.g., blood pressure and temperature, is not a static parameter, but rather changes within a range in reaction to bodily demands. Healthy cardiovascular systems are ready to quickly detect and respond to changing needs placed upon the system in order to restore homeostasis and permit directed activities. Conversely, it is often shown that invariant HR is linked to disease systems such as heart failure. HRV provides a means to assess overall cardiac health and its regulating system.

II. HEART RATE VARIABILITY

The autonomic nervous system (ANS) drives the heart rate through the sympathetic and parasympathetic branches. The dynamic balance between parasympathetic and sympathetic activity causes a continuous oscillation of the HR which is called HRV.

Periodicities in the heart rate variability (HRV) have been studied as a non invasive tool for the beat to beat quantification of the parasympathetic-sympathetic balance and thus HRV can be used as a quantitative marker of the autonomic nervous system. In addition, HRV can be considered as a reflection of various physiological factors modulating the normal rhythm of the heart.

Research has shown that:

- The HRV high frequency band is dependent on the Parasympathetic branch.
- The HRV low frequency band is dependent on both the Parasympathetic and Sympathetic branches.
- The Ratio LF/HF is a measure of the ANS balance.

The starting point for measuring the HRV is the detection of each R-peak in an electrocardiogram (ECG), and the calculation of the interval between them. HRV can simply be obtained using one chest lead ECG trace from which R to R intervals are measured in milliseconds and plotted in sequence.

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The objective of this study is to develop a DSP based signal monitoring and processing system for real ECG signals in order to investigate the determinants of frequency domain measures of heart rate variability in acute myocardial infarction. As a result, an algorithm that can detect the elements of an electrocardiogram (ECG) and determine if symptoms of myocardial infarction are present is to be developed.

First of all, a Matlab algorithm is written to prove the validity and accuracy of the design and then another algorithm is written in ***MikroC*** software that can generate a **(.Hex)** file that can be used to program the dsPIC Microchip.

III. METHODOLOGY

The processing steps involved in the spectral analysis of HRV are shown in *fig.1*. These steps are developed in "Matlab" and "MikroC" software and have proved to give good results.

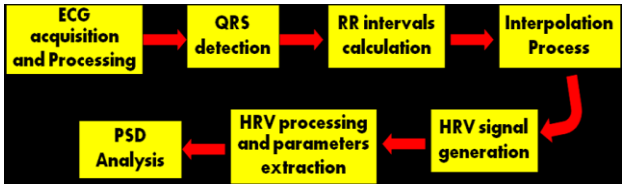

Fig. 1-Processing steps

3.1- ECG acquisition and processing

The block diagram in *Fig.2* resembles how ECG signals are taken from a patient into the machine via electrodes, then amplified and digitized and passed through a processor in order to give the known PQRST waveform.

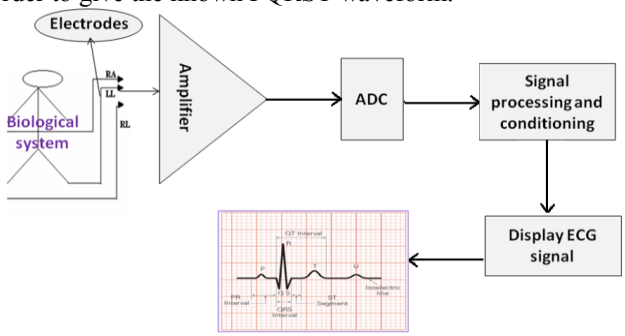

Fig. 2 –ECG acquisition and processing

3.2- QRS Detection

A QRS detection algorithm is used to detect the QRS complexes and localize the R waves. Note that this step is the most important step for diagnosis of cardiac disorders and heart-rate variability analysis. The performance of the system heavily relies on the **accuracy** of the R-peaks detector.

The signal passes successively through a sequence of processing steps that includes three linear digital filters *(Fig.3)*. First is an integer coefficient Bandpass filter composed of cascaded low pass and high pass filters with a lower and upper cut-off frequency of 5Hz and 15Hz respectively. Its function is noise rejection. Next is a filter that approximates a derivative. After an amplitude squaring process, the signal passes through a moving-window integrator over 80ms. Adaptive thresholds then discriminate the locations of the QRS complexes.

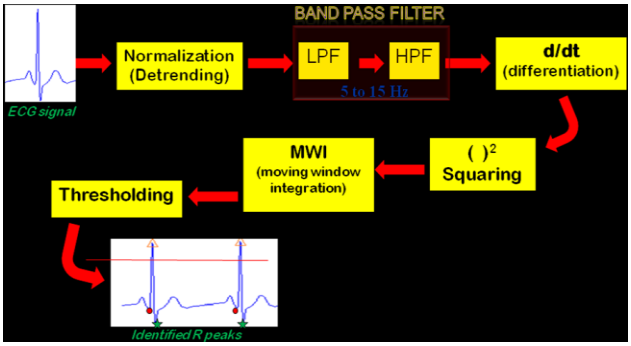

Fig. 3 –Block diagram of QRS detection

The difference equations used in programming are:

LPF : $y[nT] = 2y(nT-T) - y(nT-2T) + x(nT) - 2x(nT-6T) + x(nT-12T)$
HPF : $y[nT] = 32x(nT-16T) - y(nT-T) - x(nT) + x(nT-32T)$
Differentiation : $y[nT] = (1/8T)[-x(nT-2T) - 2x(nT-T) + 2x(nT+T) + x(nT+2T)]$
Squaring : $y[nT] = [x(nT)^2]$
MWI : $y[nT] = (1/N)[x(nT-(N-1)T) + x(nT-(N-2)T) + \ldots + x(nT)]$ ***[6]***

The threshold is calculated as followed :

```
%Thresholding
max_value = max(sig);
mean_value = mean(sig);
thresh =(sig>mean_value*max_value)';
```

3.3- RR Intervals Calculation

The sequence of RR intervals (sometimes called IBI or beat-to-beat interval) - that is, all intervals between adjacent QRS complexes resulting from sinus node depolarization, forms the RR interval time series.

The IBI time series (*Fig.4)* of an ECG segment containing N beats is given by:

$$\mathbf{RR_i = (t_{i+1} - t_i)*1/Fs;}\quad i \in \{0,2,\ldots,N-1\}$$

Where i is the sample number and Fs is the sampling frequency.

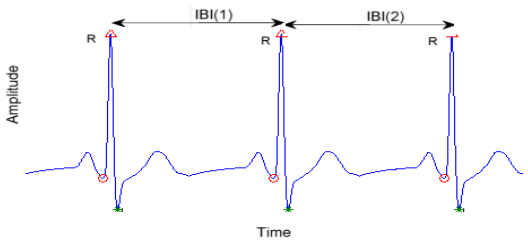

Fig.4-IBI time series

A corresponding sequence of instantaneous heart rate is defined as: $\mathbf{H\_R = 1/RR_i}$.

With the calculation of the R-R intervals or inter beat intervals, the variations of R-R intervals versus beats is determined.

3.4- Interpolation Technique

Interpolation editing methods replace the abnormal R-R intervals with new interpolated R-R intervals.

The RR interval time series is an irregular time-sampled signal (Since the time domain results are not standardized i.e. the beat occurrence itself is a random process.). This is not an issue in time-domain, while in the frequency-domain it has to be taken into account.

In addition to most Fourier based power spectrum estimates requiring signal stationarity; they also require time series that are regularly sampled in time. Spectrum estimates taken from irregularly time sampled signals can introduce additional harmonics into the power spectrum. For this reason, IBI time series must be re-sampled prior to some power spectrum estimates (the conversion from the randomly occurring event processes to uniformly sampled signals). the RR interval signal is usually interpolated before the spectral analysis to recover an evenly sampled signal from the irregularly sampled event series.

The default frequency used for interpolation was **2 Hz**. After this step, we obtained a new heart rate signal, adequate for performing the spectral analysis. This interpolation reflects the beat-to-beat variation of heart rate accurately and without any distortion *(Fig. 5and 6).*

```
%-------------------------------------------------------
%Interpolation
%-------------------------------------------------------
Dt=0.5;    % Sampling frequency: 2Hz

sigpos=R_t;  % read the signal(RR intervals)
b=[1 -1];
hrv1=filter(b,1,sigpos);
for t=0:Dt:sigpos(length(sigpos)) % Interpolation.
   if t<sigpos(1)
     vmin=1;
   else
        v1=find(sigpos<=t);
        vmin=v1(length(v1));
   end
v1=find(sigpos>=t);
vmax=v1(1);
k=round(t/Dt)+1;

   if vmin==vmax
      hrvn(k)=hrv1(vmin);
   else
hrvn(k)=(hrv1(vmax)*(t-sigpos(vmin))+
hrv1(vmin)*(sigpos(vmax)-t))/(sigpos(vmax)-sigpos(vmin))
   end
end
```

Fig.5- Interpolation –Matlab code

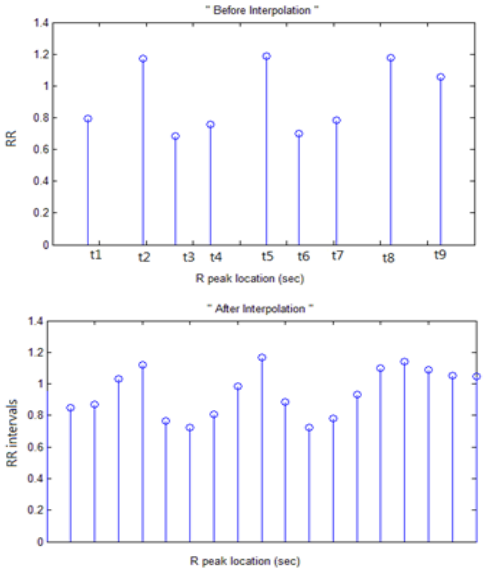

Fig.6- example of an RR data before and after interpolation

3.5- HRV Signal Generation

The frequency of interest in HRV signals is about **0.5 Hz.** The sampling frequency adequate for satisfying nyquist theory of sampling to generate the HRV signal is **2Hz**. After down sampling the inter beat interval signal to **2Hz**, **600 samples** can be obtained for **5 min** duration data for further analysis. *(fig.7)*

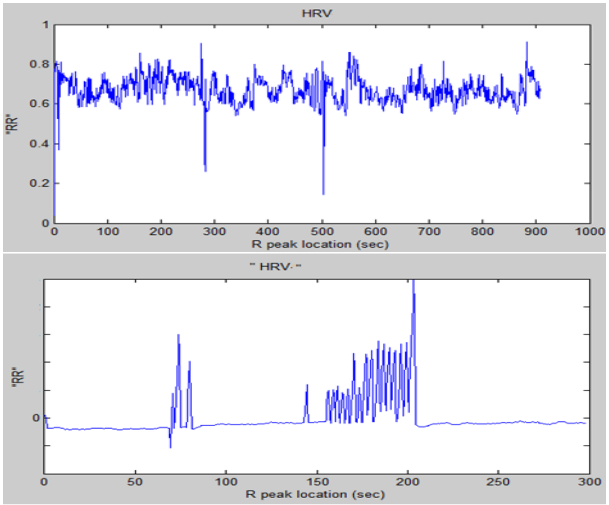

Fig.7: examples of normal and abnormal HRV signal

3.6- HRV Processing, Parameters Extraction and PSD Analysis

The frequency domain analysis method of HRV extracts frequency domain parameters from the RR interval signals. The two components of ANS, sympathetic and parasympathetic, increase or decrease the heart rate and influence different bands in the spectrum of RR intervals. Therefore, we can use frequency domain analysis to monitor the state of the ANS.

Fluctuations in HR are often thought to be periodic and occur on many time scales. Quantifying these fluctuations within the IBI time series can be done by calculating the power spectrum density (PSD). PSD presents spectral power density of a time series as a function of frequency.

Spectral analysis of HRV shows components in the **high frequency (HF)** band (0.15-0.4 Hz) that are essentially modulated by the parasympathetic branch while the low-frequency components (0.04−0.15 Hz) are affected by both. Frequencies below 0.04 Hz exist and are mainly due to the regulation process. *(Fig.8)* ***[12]***

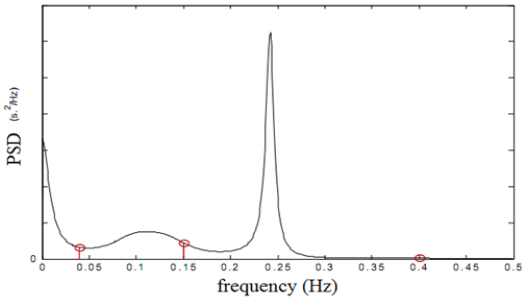

Fig.8-HRV components

The balance between sympathetic and parasympathetic outflow is often measured by the ratio of the LF and HF components **(LF/HF ratio).** This ratio has been suggested as being a marker of the sympathovagal balance.

The Matlab algorithm uses the **Welch's method** to estimate the power of the signal at different frequencies i.e., it's an approach to power spectral density estimation. Welch's method calculates PSD based on Fourier transform.

Two parameters are used in the analysis:

Parameter1: Power spectral ratio LF/HF

Parameter1 is calculated as the ratio of the summation of powers from f1 to f2 and f3 to f4. f1 to f2 and f3 to f4 represent the spectral powers in the LF and HF regions respectively.

$$\mathbf{LFHF} = \sum_{f=f1}^{f=f2} \mathbf{P(f)} \,/\, \sum_{f=f3}^{f=f4} \mathbf{P(f)}$$

P(f) is the power spectral density.

Parameter 2: Total Power TP

Another parameter that is worthy to investigate is the total power(TP) that is defined as the total summation of powers from f1 to f2 and f3 to f4, and it's equated as follows:

$$\mathbf{TP} = \sum_{f=f1}^{f=f2} \mathbf{P(f)} + \sum_{f=f3}^{f=f4} \mathbf{P(f)}$$

P(f) is the power spectral density.

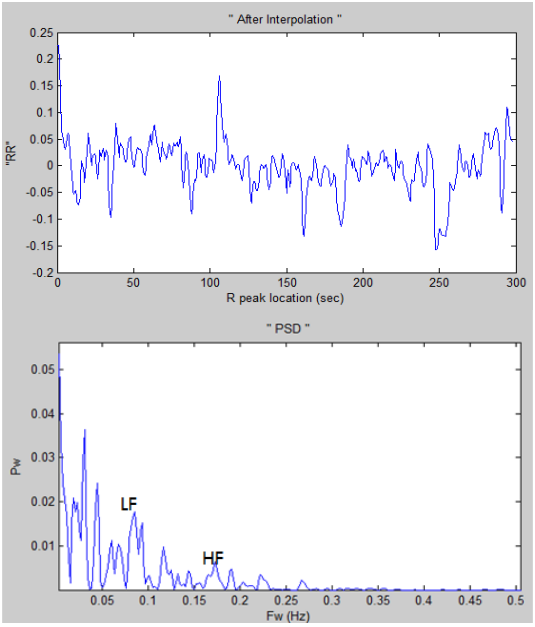

Fig.10- example of HRV and its PSD signals

IV. REAL TIME DSP IMPLEMENTATION

The adoption of digital signal processing (DSP) microchips for the detection and analysis of electrocardiographic signals offers a means for increased computational speed and the opportunity for design of customized architecture to address *real-time* requirements.

The digital signal processor used "dsPIC30F6014A" *(Fig. 9)* is a 16-bit microcontroller (MCU) architecture. This processor combines the Harvard architecture and the RISC (Reduced Instruction Set Computer) technology, is suitable for the design of embedded systems with high performance at a reduced cost. Additionally, this processor also offers many features that can ensure the effectiveness of signal processing.

Fig.9: dspic30F6014A

The *MikroElectronika* **"MikroC for dsPIC"** is a C compiler for Microchip dsPIC microcontrollers, used for software modules. The following sub-modules are constructed for our main algorithm;

- R-peaks detection program that follows the same steps discussed before.
- FFT program.
- PSD analysis program.

Thus, a system using the DSPIC30F6014A chip has been designed to realize cycle-by-cycle detection and waveform analysis using a frequency-domain technique.

V. RESULTS AND DISCUSSION

Results obtained from 50 signals has shown that the detector was able to detect practically all of the QRS complexes of real recorded signals with and without noise. The Sensitivity was calculated to be 99.5 % which shows the method has a good efficiency. The number of false detections in each case is 0%. *(Fig.10)*

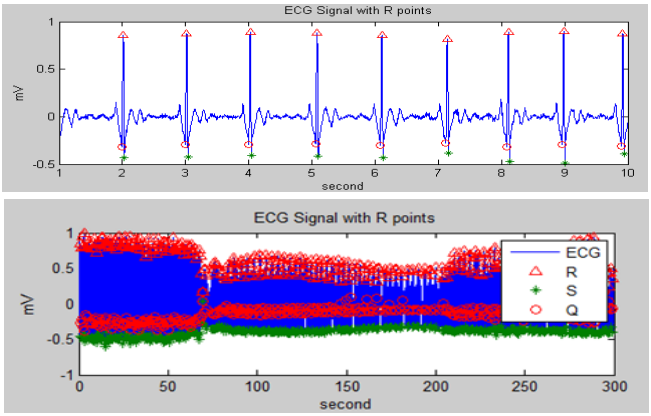

Fig.10-QRS detection (Matlab)

In addition, Testing is performed on 14 normal and abnormal signals**.** The normal ECG database are directly obtained from human subjects while the abnormal ECG datasets are obtained from the *Physionet* database [13].

Table1 shows the Results obtained from both Matlab and MikroC algorithms(both algorithms gave close results). They are in the form mean± standard deviation.

Subject	Power ratio (LFHF) Mean value ± (std)	Total power Mean value ± (std)	Remarks
Normal (N=7)	2.678±0.887	0.0028±0.0014	Healthy subjects
Abnormal-MI (N=7)	7.15±2.1	0.00083±0.00016	Potential MI subjects

Table 1-Final Results

The value of the power ratio (LFHF) for normal is found to be 2.678±0.887 and for MI patients, it is 7.15±2.1 Also the total power distributed in both LF and HF regions (TP) in normal is found to be 0.0028± 0.0014 whereas in MI patients it is 0.00083±0.00016, i.e. a significant decrease in total power distribution spectrum of the abnormal over normal subject. This is due to the reduced contractility of the myocardium at the affected areas, which projects the myocardial infarction.

Therefore the results obtained from the spectral analysis of the heart rate variability signals along with the ST segment analysis, already established fact, could predict earlier the eminent occurrence of myocardial infarction in people during routine checkup visits to the cardiologists. This all means better diagnostic tools in the hands of cardiologists and better follow up treatment.

VI. CONCLUSION

Practical trials performed at the laboratory of Lebanese University (Azm center for research in biotechnology and its application) using the available instrumentation and programming, dsPIC, Matlab simulation, modeling and assessment, and MikroC have shown reliable results in the detection of electrical signals of a human heart distinguishing between Myocardial Infarction indications and Normal readings.

Power spectral analysis of HRV signal has been carried out in 15 normal and abnormal signals. The Total power, TP, of the normal heart appears greater than that of MI. The power ratio, LFHF, is greater for abnormal signals.

As this project progressed with time, all kinds of situations from failures to disappointments, to a partial success, and finally to a probable and successful outcome bloomed and sprung out. This project was very rewarding and indicative on a personal level first, diagnostic level, and on the implementation of such techniques in the medical assessment field as well as in the industrial field.

The successful outcome of the project is the building block of future work where additional parameters could be considered.

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