A New IPFM Based Model For Artifitial Generating Of HRV With Random Input

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Abstract

The heart rate variability (HRV) signal is a useful and non-invasive tool for the evaluation of cardiovascular system and Autonomic Nervous System. Many researcher tried to model this signal. There are many different approaches for this modelling. One of the most frequently used method is Integral Pulse Frequency Modulator (IPFM) model. In IPFM model there is an input signal which is fed to an integrator and when the output of the integrator reaches to a threshold then we have a pulse. This pulse simulates the R-wave of the ECG signal. The source of ECG is sinoatrial (SA) node. SA node is affected by many factors. The power spectrum of HRV signal is divided into three main bands i.e. VLF, LF and HF. The information in these three bands shows how the Autonomic Nervous System (ANS) affects on heart activity. The ratio LF/HF is related to sampatho-vagal balance. The proposed model generates both normal HRV and HRV of some abnormalities with regard to ANS. As we used random signal in the input of the IPFM the output of the model has random variations and the output never be as a periodic signal.

Our model is very similar to real HRV than a normal IPFM. In our previous work we added the random signal to threshold and now we apply the random signal to the main input. We used Guassian random signal with zero mean with variance equals to 1.

Keywords: *Random Distribution , Heart Rate Variability Signal, Mathematical Model, IPFM Model.*

I. INTRODUCTION

ECG signal is an affective tool in diagnosis of heart diseases. Surface ECG is the recorded of potential difference between two electrodes that are on the determined surface of the skin. This biological signal gives us performance of this hiper-muscle i.e the Heart. In ECG signal the largest amplitude is R-wave. The time series which is obtained from calculation of distances between two consecutive R wave in an ECG signal provides HRV signal.
Research has shown that some disease have more effect on heart rate variability rather than ECG. In fact, this time series (RR tacogram) gives us important information about patient's physiological condition as far as performance of autonomic nervous system on heart performance. Analysis of the ability of power spectrum resulting from changes in heart rate is an effective tool for understanding this harmony, which exists in cardio-vascular[1]. As the heart acts in nonlinear manner it is preferred to use a non linear model to model heart activity. There are many kinds of model which can be used but a very simple and quite strong model is Integral pulse Frequency modulator (IPFM). The basic IPFM can not produce a random or chaotic output which is preferred because of the nature of real HRV signal. But we can use random or chaotic signal in this model. In our previous work we added random and chaotic signal in the threshold of IPFM[1,2].

II. HRV SIGNAL

HRV signal is changes in time intervals between consecutive heartbeats. In other words, the time between R- waves in two consecutives heart cycles is known as RR interval. Figure 1 shows a typical signal of HRV which is ectracted fron an ECG signal.

We can use this signal as a clinical sign in recognition of diseases. We can use the information in the HRV for assessment of mortality after heart attack [3].

Some of the sources, which affects on HRV are [4]:

- The effect of physiological controls resulting from breathing (RSA) and blood pressure (Mayer waves),
- The extent of physical and mental activists,
- Blood circulation rhythms,
- Renin angiotensin harmonic system caused by adjustments to outer cellular liquid volumes,
- The effect of various sleeping stages.

Autonomic nervous system (ANS) is a part of central nervous system (CNS). The pumping power of heart is greatly controlled by sympathetic and parasympathetic (vagal) and go to heart in great numbers. Sympathetic
nerves go from chest vertebrates and first and second vertebrates of waist from spine. After exiting vertebrates, it is divided to two important branches. The first branch is

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responsible for branching to the vessels of internal organs and heart. The second branch is responsible for branching to vessels of lateral organs. A part of these nerves that go towards the heart can

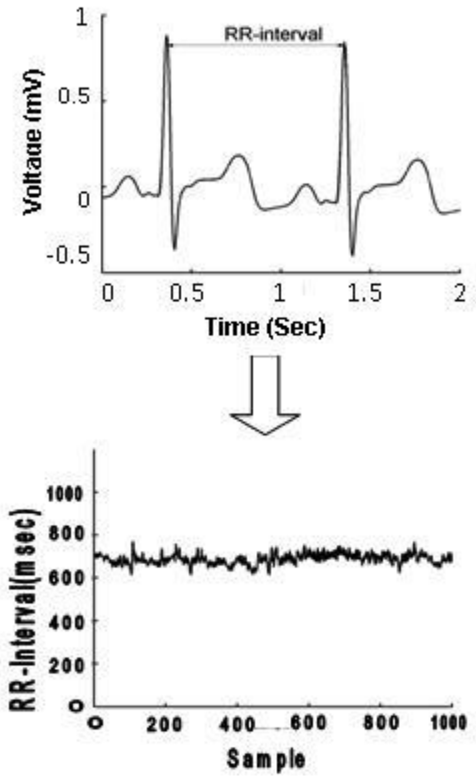

Fig. 1 ECG waveform and the way of HRV extraction from it

increase the heart beat and strength of heart through increasing provocation of heart. Sympathetic system becomes activated during stress and can cause heart rate to go to between 180 to 200 beats per minute and seldom can increase the heart beat to 250 beats per minute in young people. Upon increasing of sympathetic system heart rate and the contraction ability increases. In addition, extent of guidance of heart and duration of its contraction respectively increases and decreases. When sympathetic activity increases, we can see increases in heart rate with a five seconds delay and reaches a stable rate after about 30 seconds.

Sympathetic nerves result in above mentioned processes by secretion of norepinephrine hormone which can be summarized in three processes: 1- increase of de-charge in sinus node 2- increasing speed of guidance of message in entire heart 3- increase of power of atrial and ventricular muscles.

The branches of parasympathetic nerves go to different organs. However it can be said that in regard to sympathetic nerves system, this system has a lesser role in the process of controlling the body and is only in the control process of heart output and the effect of this nerve is noticeable.

Parasympathetic system gets activated during rest. They are able to lower heartbeat for a fewer seconds to zero, but after this time heart resumes its activities by using a process called escape-performance and continues with 20 to 40 beats per minute.

In addition to these parasympathetic nerves can decrease heart output by effecting heart muscles. Of course this effect is much lesser than pervious effect and the reason is that these nerves are located around atrium of heart, this is while the main part of heart output are creatable through ventricular[1].

Parasympathetic nerves cause two processes to occur in heart by secretion of acetylcholine hormone: 1-It decreases normal rhythm in de-charge of sinus node. 2-It decreases extent of effectuality of connecting fibers of atrium and AV node. The set of this process can cause heart output to 50% of normal under normal conditions.

In order to study the effect of sympathetic and parasympathetic activities on heart activity HRV power spectrum is usually used. Various spectrums methods have been offered from 1960's up to now for analysis of tacogram. Estimation of power spectrum (PSD) analysis creates base information, which shows how power or variance distributes as a function of frequency.

Frequency range 0.04 Hz to 0.15 Hz and Frequency range 0.15 Hz to 0.4 Hz is respectively called low frequency (LF) and high frequency (HF). In some articles domain of 0.4 is called very low frequency (VLF). It ought to be mentioned that lack of balance between sympathetic and parasympathetic system is an important sign for some heart problems [3]. Figure 2 shows a typical power spectrum of HRV.

HF element of HRV power spectrum is affected by breathing and called Respiratory Sinus Arrhythmia [5].and this part of power can be related to parasympathetic nerves. In addition, it is stated that LF power is related to barorecepetory mechanisms that are affected by sympathetic and parasympathetic mechanism. LF element is usually called Mayer Waves.

It is believed that under normal conditions at least three fluctuating system play a role in production of Mayer waves. These factors are 1- feedback system of pressure receptors 2- centrogenic rhythm in brain stem, which is related to frequency of respiration 3- autonomic fluctuating of vascular muscles [6].

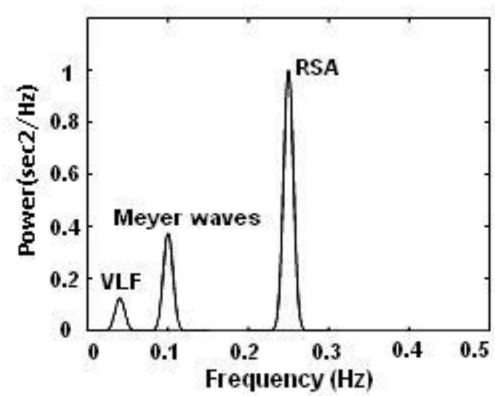

Fig. 2 A typical power spectrum of HRV

However the original source of VLF is not clearly mentioned in the papers, probably this section of power is related to environmental vascular and mechanisms of temperature adjustments.

III. IPFM MODEL

IPFM is used for modelling sinoatrial node (SAN). This simple model was introduced by Hyndman and Mohn for simulation of heart fluctuations in 1975 [7]. Part of attraction of this model is due to it is adapted with some physiological phenomena very simply.

There is an input which the IPFM integrates it until the result of integral becomes equal to threshold level (Th), at this time a plus is created in the output as a heartbeat and simultaneously integrator is reset to zero [3]. Produced pulses in output can be considered as times of R wave. The mentioned statements can be seen in equations (1).

$$Th = \int_{t_k}^{t_k+1} x(t)dt. \qquad (1\text{-a})$$

$$S(t) = \sum_k \delta(t - t_k) \qquad (1\text{-b})$$

Figure 3 shows the IPFM model diagram block [7].

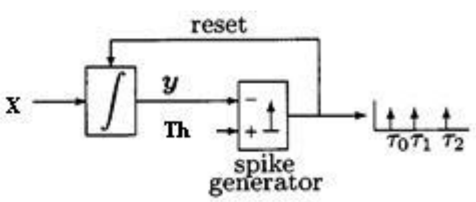

Fig. 3 The IPFM model diagram block

In 1998, heartbeats were simulated using IPFM method and effect of sympathetic and parasympathetic nerves consideration omitting their relations to one-another [3]. But in the new model that has been offered for artificial generation of tacogram RR in 2004, in addition to using IPFM, coupling of sympathetic and parasympathetic systems have been taken into consideration [8].

IV. PROPOSED MODEL

We consider four parts for the main input of IPFM. One is the level of activity of Sympathetic (S), the second is the level of activity of Paara-sympathetic (P) and the third is the internal input (i_0) and finally we have the new input which is a random signal(R). These four inputs are added and feed to the IPFM. Of course we will have the S with positive and P with negative sign because of the opposite function of these two systems. For consideration more details in the model we may consider two parts as Sympathetic system and also two parts for Para-Sympathetic system. So the final input will be as in equation (2).

$$X = S - P + I_o + R \qquad (2)$$

As mentioned before $S=S_1+S_2$ and $P=P_1+P_2$.

It should be emphasized that the main input of the IPFM i.e. X should be positive. So however we use sinusoidal changes for S_1, S_2, P_1, P_2 and I_o we add some constants to these in order to hold them positive. The other parameters in equation (3) help to reach the conditions as in physiological system.

We consider the following hypothesizes:

1. All the inputs except the random are sinosoidals.
2. If there are no input for SA node the oscillations are between 100-120 bpm. The frequency of this change is very slowly.
3. The most important contribution to changes in HRV is the effect of RSA, which is believed to be produced by fluctuations of vagal-cardiac nerve activity. It produces the HF component of the HRV power spectrum. The HR accelerates during inspiration and decelerates during expiration, an and depth of respiration bvecuase of the latent response of the sympathetic system and its low pass filtering behavior, we consider the respiration response only in the para-sympathetic system.
4. The LF component which occurs around 0.1 Hz, originates from self-oscillation in the wasomotor part of the barorefelex loops a result of negative feedback in the baroreflex. This fluctuation is synchronous with fluctuation of blood pressure and it is known as Mayer wave. This fluctuation decreases with both Paara-sympathetic and Sympathetic blockade.
5. The very low frequency (VLF) component, which is believed to arise from thermoregulatory peripheral blood flow adjustments, is caused by the sympathetic nervous system.
6. The sympato-0vagal balance affected by t he interaction of many factors, such as: central neural integration, peripheral inhibitory reflex mechanism (with negative feedback characteristics), and peripheral excitatory reflex mechanism (with positive feedback characteristic), but here we will externally control this balance changing the inputs.

The first step in this model is production of equations of the inputs (3) which formed main input of our integrator $(I_0 + S - P + R) = X$, this iunput has entered integral model IPFM and after result of integral is equal with Th(t) a pulse is

$$I_0 = a_0 + K_0 \sin(\omega_0 t)$$

$$\left.\begin{array}{l} S_1 = a_1 + K_1 \sin(\omega_1 t) \\ S_2 = a_2 + K_2 \sin(\omega_2 t) \end{array}\right\} \Rightarrow S = S_1 + S_2 \qquad (3)$$

$$\left.\begin{array}{l} P_1 = a_3 + K_3 \sin(\omega_2 t) \\ P_2 = a_4 + K_4 \sin(\omega_3 t) \end{array}\right\} \Rightarrow P = P_1 + P_2$$

created in exit as a heart beat which is indicated by s(t). Refer to (4-a), (4-b) equations.

$$\int_{t_k}^{t_k+1}(I_0 + S - P + R) = Th(t) \quad (4\text{-a})$$

$$S(t) = \sum \delta(t - t_k) \quad (4\text{-b})$$

Since each produced pulse has been taken into consideration in exit of integral isomorphic with R-wave in ECG signal thus the times between consecutive pulses can be the times between two consecutive R-waves in ECG signal. This time series constitutes HRV signal.

In second step we will calculate these times so we can produce HRV signal and then HR.

In order to obtain the desired HR, after calculating RR–intervals and finding initial HR, The result of difference between initial HR and its average is multiplied in a suitable fixed (scaling) and add with a suitable fixed amount (offset).

V. SIMULATIONS

We use the following values for the parameters in the model as in table 1.

Table1: Values of the parameters in the model

	Amplitude	Bias	Frequency
S1	.065	.41	.3141
S2	.32	.75	.6283
P1	.070	.43	.6283
P2	.398	.8	1.508
I_0	.4	2	.3141

	mean	Variance	seed
Random	0	1	.15

Fig. 4 shows the HRV signal which is generated by the model and Fig. 5 shows the power spectrum of the output HRV.

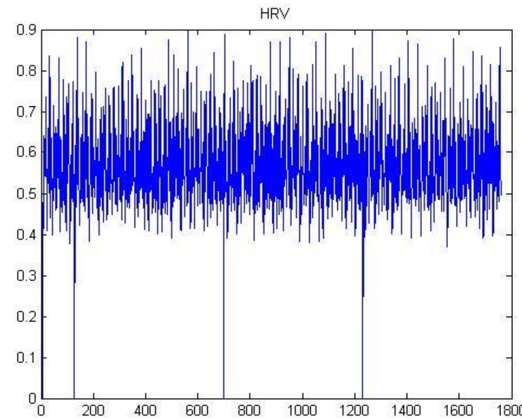

Fig. 4-a Simulated HRV

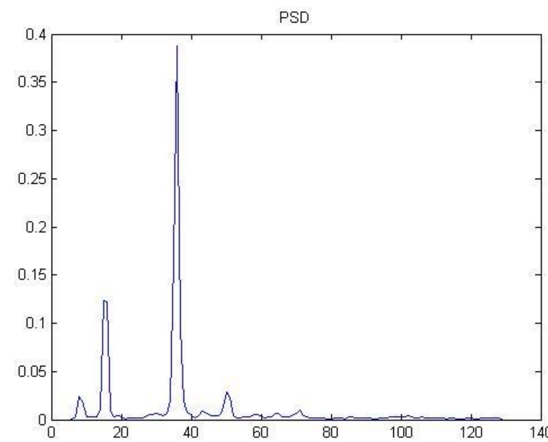

Fig. 5-Power spectrum of the output HRV

We can also simulate some sicknesses related to ANS-Heart activity by changing the values of the parameters. We successfully simulated the high balance sympathetic, high balance para-sympathetic, para-sympathetic blockade and cardio-vascular autonomy neuropathy (CAN) by proper values of the parameters.

VI. CONCLUSIONS

In the model which was proposed in this research for generation HRV, we used IPFM with a random signal in the input and got the HRV with a proper power spectrum. This HRV signal has random appearance in addition the good power spectrum. We also simulated 4 kind of sicknesses re;lated to ANS-Heart activity.

This model can be used in new generation pacemakers and helps to design controller of artificial heart valves.

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