Second Order Approximation of Heart Rate Turbulence after an Isolated Pre-Ventricular Contraction (PVC)

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Abstract

The human heart is usually a well synchronized system where certain muscle groups contract and relax at prescribed intervals. Serious cardiac problems can occur when these muscle groups do not contract, or relax, in the proper sequence. One of these ill-timed contractions, called a Pre-Ventricular Contraction (PVC), occurs when the electrical activity is initiated in a ventricle causing it to contract prematurely. The occurrence of a single isolated beat is not uncommon even in healthy subjects; however heart-rate turbulence (the after effects of a PVC) has been shown to be a powerful Electrocardiographic arrhythmia related risk predictor. The predictive value of Heart Rate Turbulence (HRT) is comparable with that of the ejection fraction of the left ventricle[1]. Heart Rate Turbulence is the physiological, bi-phasic response of the sinus node to premature ventricular contractions. [1]

When PVC's occur, the time between heart beats is greatly disturbed from its steady rate. A shortened heart period occurs, followed by a much longer beat. Beats following the PVC appear, at first glance, to have a similar period as beats preceding the PVC, but if a plot of beat number vs. time between beats (R-R interval) is formed, it can be readily seen that there are transient effects on the R-R interval lasting as many a 25 beats. Traditionally, PVC's have been characterized by two parameters: Turbulence Onset and Turbulence Slope.

The purpose of this paper is to model the response of the R-R interval to the PVC as a second-order auto-regressive model. This is done to describe the system using a more meaningful model to describe the complete transient response. Where turbulence onset and slope are chosen rather arbitrarily, and while good predictors of disease, they do not fully describe the entirety of heart rate turbulence.

Introduction

The human heart is usually a well synchronized system that certain muscle groups contract and relax at prescribed intervals. Serious problems can occur when these muscle groups do not contract, or relax, in the proper sequence. One of these mistimed contractions, called a Pre-Ventricular Contraction (PVC), occurs when the heart's left ventricle contracts prematurely. The occurrence of a single PVC is not uncommon even in healthy subjects; however heart-rate turbulence (the after effects of a PVC) has been shown to be a powerful ECG-related risk predictor. The predictive value of HRT is comparable with that of the ejection fraction of the left ventricle[1].

When a PVC occurs, the time between heart beats is greatly disturbed. A shortened heart period occurs (known as the coupling interval), followed by a much longer beat (known as the compensatory pause). Beats following the compensatory pause appear, at first glance, to have the same period as beats preceding the PVC. If a plot of beat number vs. time between

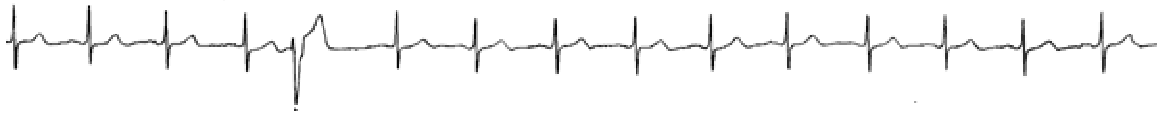


Figure 1 ECG with a single PVC

beats (R-R interval) is formed, it can easily be seen that there are transient effects on heart period (Figure 2). Traditionally, a PVC has been characterized by two parameters: Turbulence Onset and Turbulence Slope. Turbulence Onset is defined as the percentage difference between

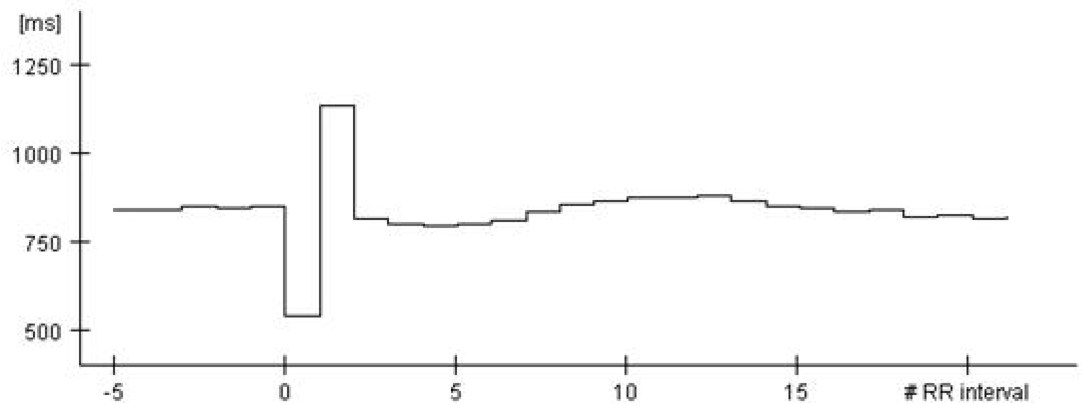


Figure 2 R-R interval for ECG with a PVC

the average value of the first two normal intervals following the PVC and the average of the first two normal intervals preceding the PVC. Turbulence Slope is defined as the steepest slope of 5 consecutive intervals following the PVC. Turbulence Slope is expressed in ms/interval. The purpose of this paper is to model the response of the R-R interval to the PVC as a second-order auto-regressive model. This is done to describe the HRT more completely and accurately. Where Turbulence Onset and Slope are chosen rather arbitrarily, and while good predictors of disease, they do not fully describe the entirety of heart rate turbulence.

Methods

Using CardioSoft[2] software, R-R interval plots were constructed from a database of long term ECG recordings. Two other long term R-R interval records were obtained from TUM[1] at www.h-r-t.org. PVC's in the two TUM records had previously been identified. PVC's occurring within 15 R-R intervals of a preceding PVC were excluded from analysis due to transient effects of the previous PVC present in the latter response. Furthermore, R-R recordings were excluded that did not contain at least 3 isolated PVC's. This was done to ensure an average of PVC responses so that an adequate model could be constructed. Two ECG recordings from the CardioSoft[2] database were fit to our constraints. One recording contained 4 isolated PVC's, the other contained 10. Both patients are over 60 years in age with unknown cardio logical problems. Two TUM(ecg_1 and ecg_3) records also fit our constraints, for a total of 4 valid records.

Analysis

Once isolated PVC's of sufficient number were identified in patient records, analysis of meaningful records could begin. To normalize PVC's, a 6-point mean was taken of the six R-R intervals immediately preceding a PVC, and removed from the resulting PVC response. This ensures that an autoregressive model with no offset could be formed. For each record the resulting PVC responses were averaged, giving a composite turbulence response, unique to the patient. Prony's method was used to compute a 2 pole, no-zero model to a PVC. We assumed that a HRT can be modeled as an impulse function, resulting in an impulse response. The average PVC was used as the impulse response input to Prony's algorithm, as evaluated using Matlab. The Levinson-Durbin, Steiglitz-McBride, and Burg methods were also evaluated. Each of these four algorithms is standard Matlab functions. Result's for the Prony's method evaluation fit the data the best and are discussed below. From the coefficients of the resulting 2nd order transfer function (Prony's method), the damping factor and natural frequency were found for each patient record.

Results

Four patient records were examined to determine the second order response to an isolated PVC. CardioSoft Patient N3828-26 is a 27 year old male with an unknown heart condition. CardioSoft Patient PH-170 is a 43 year-old male with an unknown heart condition. Figures 3(a) and (b) show long term R-R intervals for patient N3828-26 and PH-170, respectively. No patient data were available for TUM patient ecg_1 or ecg_3. RR intervals for ecg_1 and ecg_3 are shown in Figure 3(c) and (d), respectively.

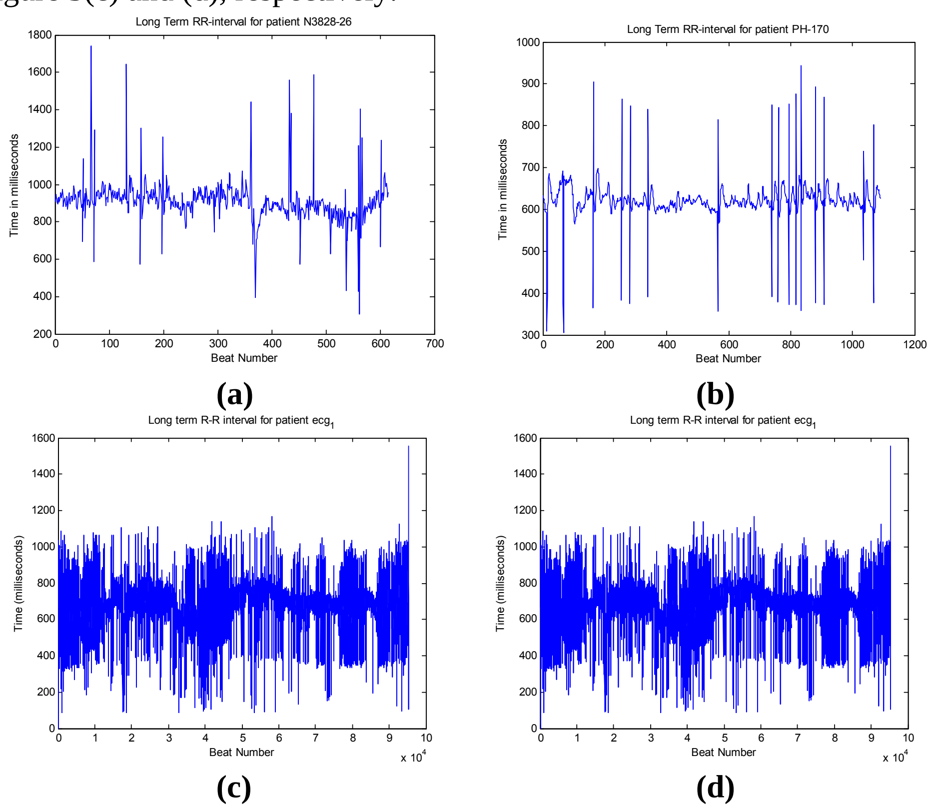


Figure 3 R-R intervals for patients (a) N3828-26, (b) PH-170, (c) ecg_1, and (d) ecg_3

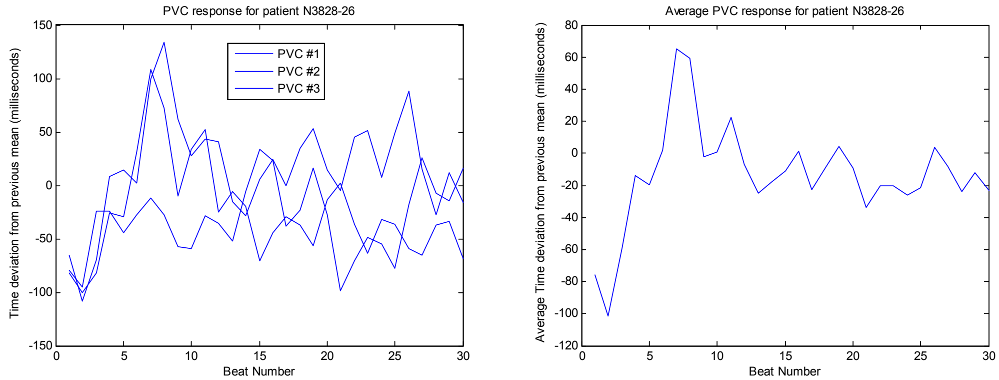


Figure 4 (a) raw PVC response and (b) average response for patient N3828-26

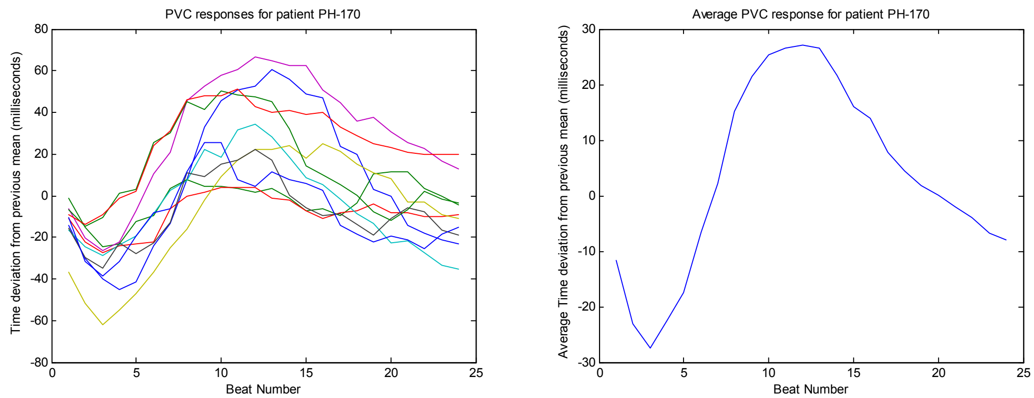
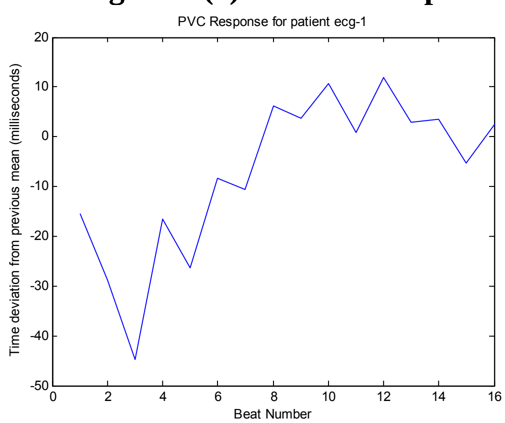


Figure 5 (a) raw PVC response and (b) average response for patient PH-170



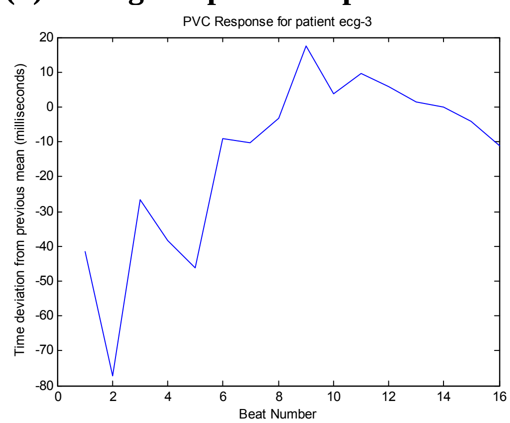


Figure 6 average response for patient ecg_1 **Figure 7 average response for patient ecg_3**

From the data shown in Figures 4(b), 5(b), 6, and 7, 2nd order models were computed using Prony's method. Figures 8(a) – 8(d) show 2nd order models of PVC responses and the average PVC response from the studied patients. From the coefficients of the model, damping factors and natural frequencies were calculated for the patients' PVC response curves. Table 1 shows the model coefficients, damping factors, and natural frequencies for both patients.

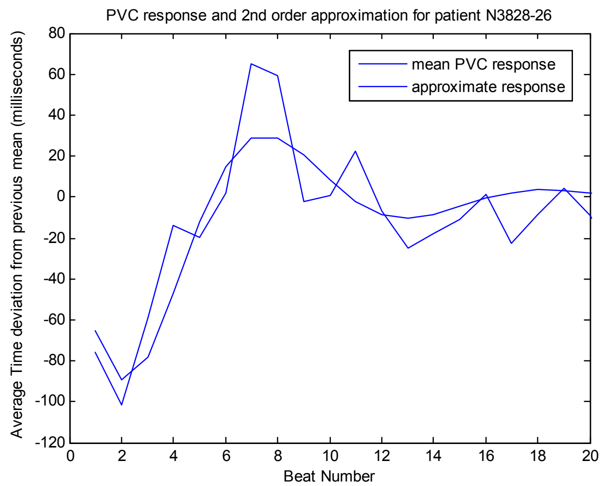


Figure 8 (a) 2nd order approximation of PVC response for patient N3828-26

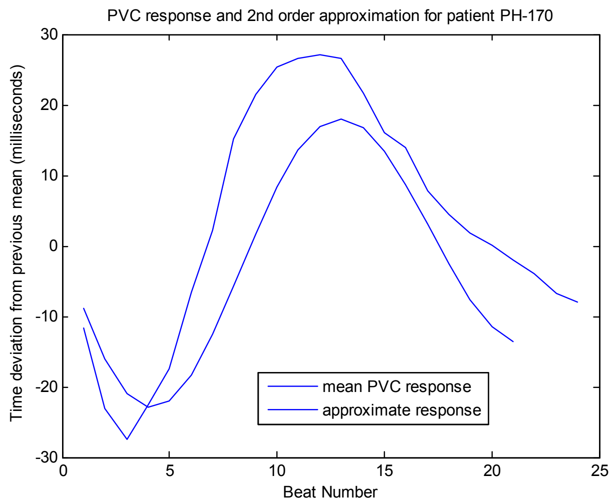


Figure 8 (b) 2nd order approximation of PVC response for patient PH-170

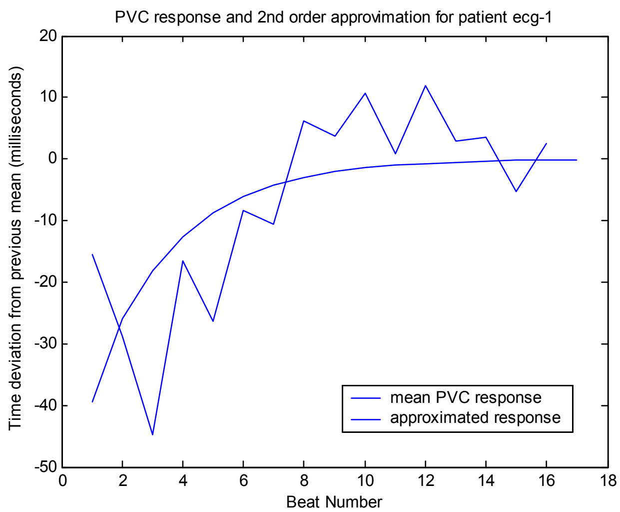


Figure 8 (c) 2nd order approximation of PVC response for patient ecg_1

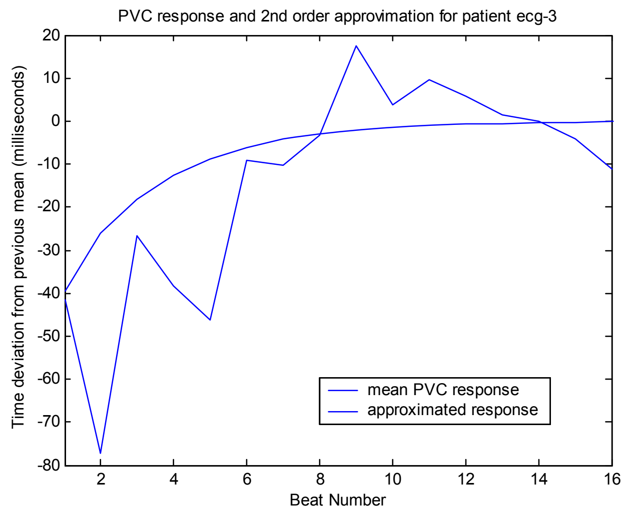


Figure 8 (d) 2nd order approximation of PVC response for patient ecg_3

Table 1: Model Parameters for PVC response

	2nd Order Model [h(z)]	**Damping Factor**	**Natural Freq.(rad/s)**
Patient N3828-26	$\dfrac{-65.512}{1-1.36z^{-1}+0.669z^{-2}}$	-.835	8.18
Patient PH-170	$\dfrac{-11.678}{1-1.69z^{-1}+0.811z^{-2}}$	-.937	.973
Patient ecg_1	$\dfrac{-15.612}{1-0.5193z^{-1}-0.2673z^{-2}}$	—	—
Patient ecg_3	$\dfrac{-39.54}{1-0.6581z^{-1}-0.0259z^{-2}}$	—	—

Conclusions

A second order approximation of the heart period transient response to a PVC was adequately modeled with an AR model. Another parameter not used for analysis in this paper, but possibly of great importance to fine tuning of the eventual diagnosis procedure is the average heart rate preceding the PVC beat. It intuitively follows that a patient's heart beating with a relatively fast heart rate would react differently to a stimulus (such as a PVC) than a patient's heart beating at a slower heart rate[3].

Future Work

In the traditional PVC classification scheme (Turbulence Onset/Slope method), prediction rates for certain serious conditions are good (greater than 80% diagnosis rate). The proposed solution to PVC modeling is not necessarily a replacement for more traditional methods, but possibly a broader method for disease/arrhythmia diagnosis. Our hypothesis is that a second order model with damping factors and natural frequencies will provide additional information on the reflex loop including baroreceptor sensitivity. Of course, to determine if this method will be successful in diagnosing various disease states, more data must be collected and analyzed. Foremost, a group of healthy patients should be studied to determine a healthy response. A larger data set is needed to determine the effects of average heart rate preceding the PVC, blood pressure, age, as well as patient to patient differences between patients with similar physical attributes (age, disease, etc.).

References

1. Technische Universität München (TUM), "Heart Rate Turbulence." <http://www.h-r-t.org/hrt/en/index.html>. April 10, 2003

2. CardioSoft, <http://www.cardiosoft.com/>

3. Hallstrom, A.P.; Stein, P.K.; Schneider, R.; Hodges, M.; Schmidt, G.; Ulm, K.; Characteristics of heart beat intervals and prediction of death. Inter. J. of Cardiology, 100: 37-45, 2005

Brian Oliver is a recent graduate of Arkansas Tech University. He is currently working as a Junior Engineer for Ad Astra Technologies, Inc. Ad Astra Technologies is developing the VASIMR rocket at Johnson Space Center, Houston, TX.