Computational Analysis of Synthetic Cardiac Signals

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Abstract. *The electrocardiogram (ECG) is a time-varying signal reflecting the ionic current flow which causes the cardiac fibers to contract and subsequently relax. A normal cycle of the ECG represents the electrical activity which occurs with every heartbeat. In this paper we have compared synthetic ECG, obtained from two different models, to the real data obtained from a normal heart. The synthetic data were generated from (i) the Fitzhugh-Nagumo equations and (ii) MCTS dynamical model. Analyzing the recurrence plots we see that neither of the two models represents, with good accuracy, the cardiac dynamic behind the ECG variability patterns. From the asymmetry spectra conjugating the Gradient-Pattern Analysis and Wavelet Db8 decomposition we show that the MCTS dynamical model is close, than the Fitzhugh-Nagumo (FN) description, to the real ECG variability pattern. However, controversially, the Detrended Fluctuation Analysis shows that the FN closest to the real data. Although the Fitzhugh-Nagumo model can capture the electrical characteristics of the heart beat, it is not able to represent the PQRST wave's morphology in detail. In the MCTS dynamical model this limitation is solved taking into account the 3D cycle dynamics explicitly. In the other hand, in both descriptions the structural complexity in the cardiac membrane can be not well represented. Thus, based on the Gradient Spectra methodology, we present a preliminary approach for ECG modeling validation discussing the application of computational tools to assess biomedical signal analysis which is used to classify clinical statistics from both real and synthetic ECG.*

1. Introduction

The field of biomedical signal processing provides a number of techniques for assisting physicians with their everyday tasks of diagnosing and monitoring medical disorders. Analysis of the electrocardiogram (ECG) provides a quantitative description of the heart's electrical activity and is routinely used in hospitals as a tool for identifying cardiac disorders [McSharry, 2005]. Ionic models that describe ventricular action potential (that is shown in the ECG) have become increasingly more complex and hopefully more realistic as a result. One traditional alternative to avoid this complexity has been to employ simplified models of excitable media as ''caricatures'' of myocardium. The best known example is the Fitzhugh–Nagumo model (FN). The FN model has been (and remains) extremely useful to gain basic insight into the wave behavior of generic excitable media, and in particular to understand how this wave behavior depends on a reduced set of parameters [Fitzhugh, 1961, Nagumo, 1962]. In another scenario, following a wave description for the cardiac dynamics, the MCTS dynamical model is a new way of

modeling the cardiac activity. This model is based in three coupled ordinary differential equations. It generates a trajectory in a three-dimensional (3-D) state–space and claims to simulate synthetic realistic ECG [McSharry, 2005]. In this work we use the Gradient Spectra approach and the Detrended Fluctuation Analysis (DFA) in order to characterize and compare these different models of the heart activity with real ECG signals.

2. Methodologies

In order to obtain synthetic ECG signals we have considered two different approaches: (i) The first model is the solution of the 2D Fitzhugh-Nagumo equations using the Finite Difference Method and a recovery from Clayton's results in 3D [Clayton, 2000]. (ii) The second model is based on the equations of the MCTS Dynamical Model, solved using fourth-order Runge-Kutta method, which is adapted from McSharry's program (*http://physionet.org/physiotools/ecgsyn/*). The real data was acquired from the Physionet database (MIT-BIH Normal Sinus Rhythm Database), from normal patients.

The Asymmetry Spectra is an approach that conjugating the Gradient-Pattern Analysis and Wavelet Db8 decomposition. The asymmetry coefficient is calculated in each frequency resulting from the wavelet discrete decomposition. We compute the mutual information distances between the average of eleven gradients of the normal series and the synthetic series obtained from the cardiac models: (i) the Fitzhugh Nagumo model and (ii) MCTS dynamical model. As a complementary analysis, the method of DFA has proven useful in revealing the extent of long-range correlations in time series. The time series to be analyzed (with N samples) is first integrated and next, the integrated time series is divided into boxes of equal length. In each box of length n, a least squares line is fit to the data (representing the trend in that box) from where it is possible to compute the Hurst coefficient [Peng, 1994].

3. Results

The Detrended fluctuation of the normal series was about 0.049, from MCTS dynamical model was 0.122 and from Fitzhugh-Nagumo model was 0.048, from the digitalized signal and 0.194, from the solution in 2D. The distance between the mean gradient of the normal series and the synthetic series is shown in the table 1. From these results, we calculate how much the series proceeding from a model can approximate from the normal series.

Table 1. The mutual information distances

Series	Distance
Fitzhugh-Nagumo in 2D	4.10 -- 65%
Fitzhugh-Nagumo in 3D	5.12 -- 56%
Mean of the series from the MTCS model	5.20 -- 55%
MTCS model with 1% of noise	2.55 -- 77%
MTCS model with 2% of noise	5.64 -- 51%

In the figures below we can verify that the dynamical MTCS model can be closer to some normal series while the Fitzhugh-Nagumo model can be closer to others normal series.
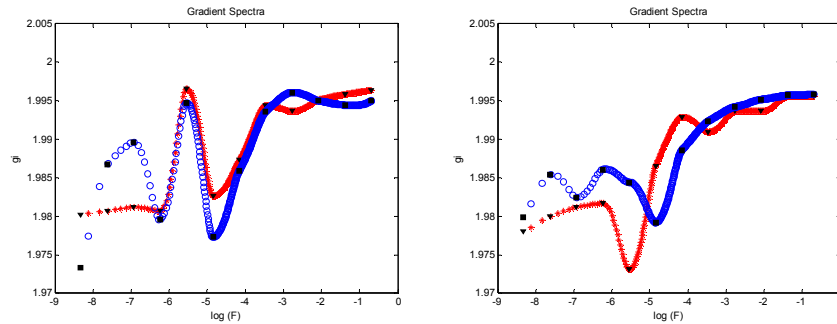
Figure 2. Gradient Spectra of (i) a normal serie and the mean of synthetic series from MCTS model and (ii) the serie from the Fitzhugh-Nagumo model and the mean of the normal series.

4. Discussion

Although the Fitzhugh-Nagumo model can capture main electrical characteristics of the heart beat, it has been recognized that this model does not reproduce, even qualitatively, certain important fine properties of ventricular action potential. As a result, modified forms of the FN equations, truncated versions of more complex models and new alternatives for the modeling have been introduced [Fenton and Karma, 1998]. In the MCTS dynamical model this limitation is solved taking into account the 3D cycle dynamics explicitly. Then, even these models can represent some ECG characteristics; they are not able to capture fine response of the system that can be important for a high resolution characterization when external fields can be also driven, at some level, the cardiac dynamics (e.g. the gravitational field). Thus, it is an initial study about the better model to be considered in this research to represent the cardiac activity through the ECG signals. Other models can also be considered, like the Fentom-Karma model and Van der Pol chaotic oscillator.

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