# An Open-Source Method for Simulating Atrial Fibrillation Using ECGSYN

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## Abstract

*A method for simulating atrial fibrillation has been developed using the open source simulator ECGSYN (available at physionet.org). In this method episodes of atrial fibrillation are simulated by combining data streams generated by two ECGSYN engines driven from a correlated stochastic process. The underlying process represents atrial activity during atrail fibrillation. This process generates a series of atrial inter-beat intervals with the same statistical properties as those found in real patients with atrial fibrillation. The atrial beats from this process are then selected to be either conducting beats that generate subsequent ventricular activity on non-conducting beats that generate only atrial activity. The intervals for conducting beats are processed by an ECGSYN engine with appropriate parameters to create PQRS and T waves while the non-conducting intervals are processed by a second ECGSYN engine with parameters to generate only P waves. The data streams from the two engines are superimposed to create an artificial atrial fibrillation waveform. This waveform generator has been made into an operator and has been incorporated into a stream based ECG simulator. The simulator uses a timing operator to switch from generating normal ECG morphologies to atrial fibrillation.*

## 1. Introduction

When testing signal processing algorithms for analysing biomedical signals, it is helpful to know the underlying dynamics of the waveform being tested [1, 2]. A realistic artifical biomedical signal generator that is able to encompass the range of signals observed for both normal and abnormal subjects is therefore a useful tool. The ability to rapidly create a regenerateable noise-free time series enables a researcher to quickly prototype applications and test hypotheses [1, 2]. Furthermore, algorithms can be tested under unusual circumstances for which there may be limited real data, or for when intrinsic noise levels are high.

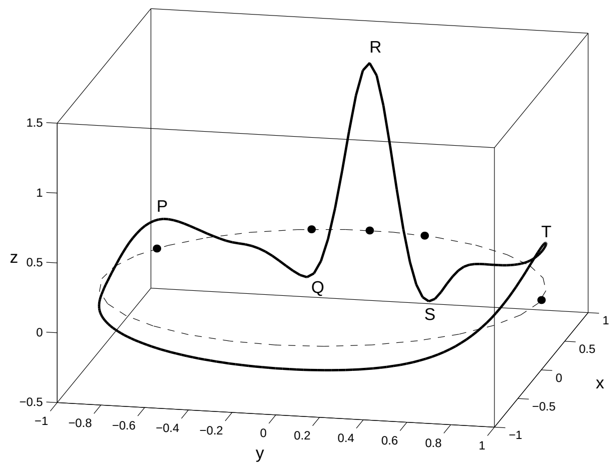


Figure 1. A typical trajectory generated by the dynamical model (1) in the three-dimensional space given by $(x, y, z)$. The dashed line reflects the limit cycle of unit radius while the small circles show the positions of the P,Q,R,S,T events.

In this paper we present a method for generating a simulated atrial fibrillation (AF) signal using the superimposed output of two ECGSYN engines. This method is based on an atrial fibrillation model proposed by Zeng and Glass [3] in which a number of atrial waves conduct and cause ventricular activation. To create a synthetic AF signal we first generated a series of atrial beat intervals using the ECGSYN program *rrprocess* with statistical parameters from real patients with AF[3]. We then determined which of the intervals generated by this process would be conducting vs. non-conducting. Two ECGSYN engines with customized parameters separately processed the conducting and non-conducting intervals to generate two ECG waveforms. These waveforms were then superimposed to create the synthetic AF signal.

Table 1. ECG & model parameters for normal beats in (1). $\beta = \frac{\sqrt{\mathrm{HR}}}{60}$

| Index (i) | P | Q | R | S | T |
|---|---|---|---|---|---|
| Time (s) | -0.2 | -0.05 | 0 | 0.05 | 0.3 |
| $\theta_i$ (rads) | $-\frac{1}{3}\pi\sqrt{\beta}$ | $-\frac{1}{12}\pi\beta$ | 0 | $\frac{1}{12}\pi\beta$ | $\frac{1}{2}\pi\sqrt{\beta}$ |
| $a_i$ | 1.2 | -5.0 | 30.0 | -7.5 | 0.75 |
| $b_i$ | 0.25$\beta$ | 0.1$\beta$ | 0.1$\beta$ | 0.1$\beta$ | 0.4$\beta$ |

## 2. The ECG model

The ECG is generated by fourth order Runge-Kutta integration [4] of three ordinary differential equations (eq. 1) in 3 dimensions, $x, y, z$. Movement in the $(x, y)$-plane corresponds to isoelectric activity (see Fig. 1). By placing five *events* around the limit cycle which act as negative or positive attractors/repellors, the waveform is made to move away from the isolelectric line with a Gaussian morphology related to the model parameters. These events correspond to the distinct points on the ECG; the P,Q,R,S and T. These events are placed at fixed angles along the unit circle given by $\theta_P$, $\theta_Q$,$\theta_R$,$\theta_S$ and $\theta_T$ (see Fig. 1). The dynamical equations of motion are given by

$$\begin{aligned} \dot{x} &= \alpha x - \omega y, \\ \dot{y} &= \alpha y + \omega x, \\ \dot{z} &= -\sum_{i \in \{P,Q,R,S,T\}} a_i \Delta\theta_i \exp(-\Delta\theta_i^2/2b_i^2) - (z - z_0) \end{aligned} \quad (1)$$

where $\alpha = 1 - \sqrt{x^2 + y^2}$, $\Delta\theta_i = (\theta - \theta_i) \bmod 2\pi$, $\theta = \mathrm{atan2}(y, x)$ and $\omega$ is the angular velocity of the trajectory as it moves around the limit cycle. The ECG is reproduced using the motion of the trajectory in the $z$-direction. See [5] and [1] for a full description of the model.

The beat-to-beat variation in the morphology is induced by the variation in the integration step $dt$ to reflect changes in the RR interval; the time to complete one revolution around the attracting limit cycle in the $(x, y)$-plane. Shorter RR intervals (higher HR's) compress the waveform, resulting in shorter QT intervals and lower RS amplitudes (i.e. RSA). To mimic Bazett's law, a further compression factor is added; the $\theta_i^{BP}$ are therefore pre-multiplied by a factor proportional to $\beta = \sqrt{\mathrm{HR}}/60$, causing a decreasing delay between the $\theta_i^{ECG}$ and the $\theta_i^{BP}$ for increasing mean HRs.

### 2.1. AF model

The AF model begins with the generation of a series of atrial beat intervals. This was accomplished using the Matlab version of the ECGSYN *rrprocess* function as follows:

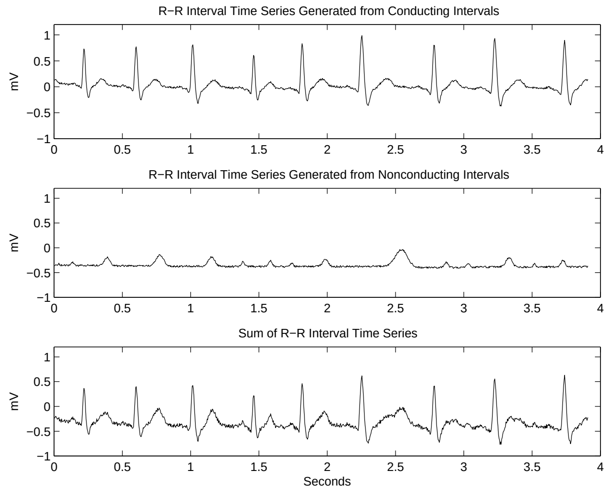


Figure 2. The model for synthetic atrial fibrillation (bottom) is the sum of the conducting atrial beats (top) and the non-conducting beats (middle)

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[rrp]=rrprocess(256,256,0,410,94,0.5,256)
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The variable $rrp$ now contains an atrial beat time series with the statistical properties of data taken from patients with AF. From this process atrial intervals are next assigned to be either conducting or non-conducting according to the following rules:

- The first atrial beat is conducting.
- An atrial beat occurring during ventricular activity is non-conducting.
- Otherwise, a beat has a 76% chance of conducting.

The value for the probability of conduction after the cessation of ventricular activity, $76\%$ was determined experimentally as the probability that resulted in a similar ratio (three to one) of atrial to ventricular beats as derived from data from AF patients[3].

To generate synthetic AF signal, the conducting and non-conducting intervals were then separated and used to seed two different ECGSYN engines. The conducting interval time series was processed by an ECGSYN engine with parameters $a_i$ and $b_i$ (see Table 2) to generate PQRS and T waves for every interval. The non-conducting interval time series was processed by an ECGSYN engine with parameters $a_i$ and $b_i$ (see Table 2) set to generate only P waves for every interval as described in Table 2. These two synthetic ECG signals were then superimposed to create a synthetic AF signal as shown in Figure 2.

## 3. Discussion and future work

The results of the synthetic AF generation are visually and statistically similar to real signals taken from real

Table 2. Modified ECG & model parameters in for generating synthetic AF where $a_1$ and $b_1$ are the parameters used for the conducting intervals and $a_2$ and $b_2$ are the parameters used for the non-conducting intervals.

| Index (i) | P | Q | R | S | T |
|---|---|---|---|---|---|
| $a_1$ | 0.5 | -5.0 | 30.0 | -7.5 | 0.5 |
| $b_1$ | $0.1\beta$ | $0.1\beta$ | $0.1\beta$ | $0.1\beta$ | $0.4\beta$ |
| $a_2$ | 0.5 | 0 | 0 | 0 | 0 |
| $b_2$ | $0.2\beta$ | $0.9\beta$ | $0.9\beta$ | $0.9\beta$ | $0.9\beta$ |

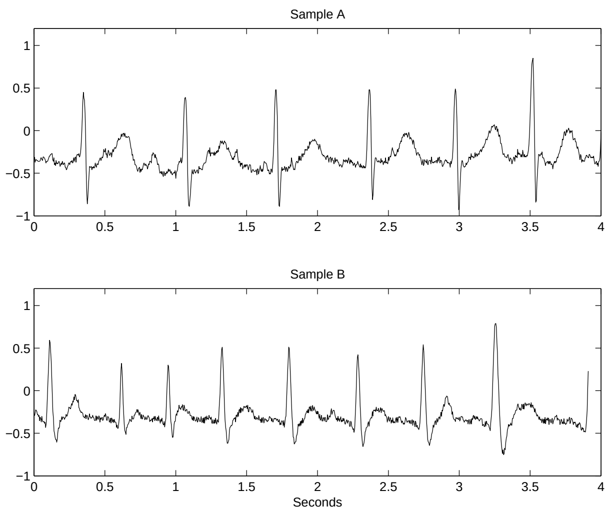


Figure 3. A comparison of natural atrial fibrillation (Sample A) with a segment of synthetic atrial fibrillation (Sample B)

patients with AF. Figure 3 shows a comparison of a real atrial fibrillation signal (samples 5706021 through 5707021 of record 04746 of the MIT-BIHdvips atrial fibrillation database (afdb)[6]) with a signal generated using this synthetic AF model. This model was created to test a real-time stream processing system for processing physiological signals[7]. To improve the model in the future we are considering a more sophisticated model for determining which of the atrial beats are conducting beats, following more closely the ideas presented by Zeng and Glass[3].

## 4. Author's note

Open source C, Matlab and Java code for the models is available from Physionet [8].

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