fecgsyngui: A GUI Interface to *fecgsyn* for Simulation of Maternal-Foetal Activity Mixtures on Abdominal Electrocardiogram Recordings

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Abstract

This paper describes, a graphical user interface (GUI) for synthetic simulation of maternal-foetal ECG mixtures. The GUI is directly linked to the previously introduced fecgsyn ECG model, which was used for producing a subset of data of the Physionet/Computing in Cardiology Challenge 2013. fecgsyngui serves as a tool that facilitates the use of the broad capabilities of fecgsyn.

ECG mixtures can be generated with realistic beat-to-beat variability, morphology, amplitude modulation due to respiration and foetal movement. The GUI allows the user to visualise and generate a set of realistic scenarios to stress test and train separation and detection algorithms. Electrodes can be placed on the maternal abdomen using an interactive geometric representation. Simulation parameters and generated signals can be exported to .mat files for further processing.

Using the underlying model, noise sources, ectopic beats, and multiple foetuses can be added. A series of pathological scenarios for situations (described in the original publication) for which data collection is problematic in reality, are included. These can be further customised to mirror specific pathological situations.

1. Introduction

Accurate extraction of foetal electrocardiogram (FECG) morphology using non-invasive measurement remains an open problem. This is in part due to the lack of publicly available databases including expert-labeled foetal QRS complexes and other morphological markers. This shortage of datasets makes the development of robust FECG signal extraction algorithms difficult.

In this paper, we present a graphical user interface (GUI) which complements the *fecgsyn* foetal ECG simulation toolbox described in our earlier work [1]. For specific details on the model, the reader is referred to this publication. An early version of the *fecgsyn* was used for producing a subset the Physionet/Computing in Cardiology Challenge 2013 database [2, 3]. *fecgsyn* is an extension of the ECG model introduced by McSharry *et al.* [4] and brought into the FECG scope by Sameni *et al.* [5]. The GUI was developed using MATLAB 2013a (Mathworks, Natick, USA) and is freely available for download on Physionet.org [6] (under the GNU General Public License) together with the underlying toolbox. The GUI can be run stand-alone using the MATLAB Compiler Runtime environment.

2. User Interface

The user interface consists of two windows. The first window, the ***display window***, shown in Figure 1 contains controls for running predefined scenarios, loading previously saved data and displaying the simulation results. The second window, the ***customization window*** shown in Figure 2, allows the user to define parameter values to tailor the simulation.

2.1. Display Window

The primary panel, ***panel A1***, on the display window (see Figure 1) shows plots of the resulting maternal-foetal ECG mixtures. These can be manipulated using standard MATLAB plotting tools located below the menu bar. The active plot being displayed can be chosen from the list in ***panel B1***. If multiple plots are available, e.g. for each electrode, these can be selected from the list in ***panel C1***.

Panel D1 contains basic GUI controls, used to select a scenario and to run the simulator. One of the pre-defined scenarios, described in Section 3, can be selected from the drop-down menu. It can be run as-is by clicking the ***Run*** button, or customized by clicking the ***Customize*** button. The latter option opens the customization window described in Section 2.2. The results of a simulation and corresponding model parameters can be exported in the MATLAB .mat format, using the ***Export*** button. Previously exported simulations can be imported back into the GUI for display purposes, using the ***Import*** button.

2.2. Customization Window

Panel A2 contains the general parameter panel with two variables: ***n***, the total number of samples, and ***fs*** the sampling frequency. The shortest segment that can be generated is 15 seconds.

Panel B2 includes information regarding the foetuses. ***fheart*** specifies the foetal heart position in cylindrical coordinates. The actual location is randomly chosen (from a uniform distribution) around these coordinates within a small sphere (radius = 0.01). ***fhr*** specifies the average foetal heart rate in beats per minute (bpm). ***facc*** specifies the foetal acceleration/deceleration rate in bpm. The type of acceleration/deceleration can be set by using the ***facctype*** drop down box to one of the following options: 'none', 'nsr', 'tanh', 'mexhat', or 'gauss' (for more details see [1]). The ***fectb*** checkbox selects whether ectopic beats should be present in the foetal ECG (with the default state transition matrix of the Hidden Markov Model defined in [1]). To model respiration, the respiratory frequency of the foetus in Hz can be set in the ***fres*** field. Foetal movement can be simulated by selecting one of 'none', 'linear', 'spline' or 'helix', from the ***ftraj*** drop down menu. ***fvcg***, the foetal vectorcardiogram number, can be set from 1-9. Each ***fvcg*** corresponds to the model Gaussian parameters extracted from VCGs of different individuals (refer to [1] for mode details). The number of foetuses can be varied using the "Add foetus" and "Remove foetus" buttons to simulate multiple pregnancies. Each foetus can be described individually, by first selecting the appropriate foetus from the list, and then editing its corresponding parameters.

Panel C2 contains parameters specific to signal noise. The signal to noise ratios of the FECG relative to the maternal interference, and the signal to noise ratio of the MECG to noise, can be set using the ***SNR_fm*** and ***SNR_mn*** fields. Noise sources can be added and removed using the "Add Noise Source" and "Remove Noise Source" buttons. Each noise source can be edited by selecting it from the noise source list. For each noise source, the noise type can be set from the ***ntype*** drop down menu. Additionally, the noise modulation function can be set freely in the ***noise_fct*** field, as a function of time "t" (seconds) (e.g. $2 \times \sin(t)$).

Panel D2 contains characteristics related to the maternal heart. Similarly to the foetal parameters in panel B, heart position, heart rate and acceleration/deceleration, acceleration/deceleration type, ectopic beats, respiration frequency and vectorcardiogram number can be set by the user.

Panel E2 contains three buttons: (1) ***Run*** will initiate the simulation using the custom parameters, as set by the user and opens the display window. ***Edit*** allows the editing of a preset scenario, which can be useful if one of the scenarios closely match the requirements of the user. These parameters are copied into the custom scenario, and can be edited. The ***Back*** button returns the user to the display window.

Panel F2 contains a list of predefined scenarios, which can be selected by clicking on the appropriate entry in the list. Additionally, the ***Save*** and ***Load*** buttons allow the user to save a MATLAB .mat file containing custom parameter values, and to load previously save parameter values, respectively. The saved .mat files can be inputted to the $run\_ecg\_generator.m$ function of *fecgsyn* to reproduce all the plots available on the GUI or simply loaded in the MATLAB environment for further manipulation.

Panel G2 contains the electrode locations. This can be visualised, using the ***Preview*** button, which opens Figure 3. The electrodes are shown as blue squares and are numbered sequentially. The number of electrodes used, can be set using the ***Number of electrodes*** drop-down menu. If more than six electrodes are selected, the arrow buttons at the bottom of the panel can be used to turn the page to the next set of electrodes. For each electrode, the position is set using cylindrical coordinates: angle ***θ*** and height ***z*** while the radius is always 0.5 which corresponds to the electrodes being on the surface of the cylinder. The view of the plot can be manipulated using default MATLAB plotting tools below the menu bar.
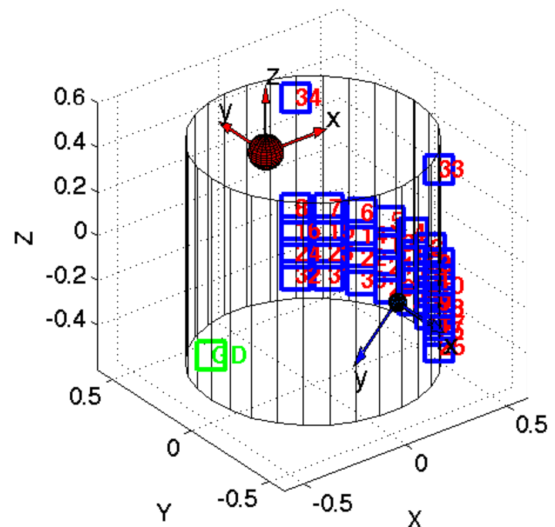

Figure 3.   Graphical representation illustrating the locations of the maternal (upper circle) and foetal (lower circle) hearts in the VCG coordinate frame, respectively. Blue boxes, located on the maternal abdomen, indicate electrode positions and are numbered for the corresponding output channel. All electrodes are unipolar. The referenced electrode, on the back of the mother, is indicated by the green block.
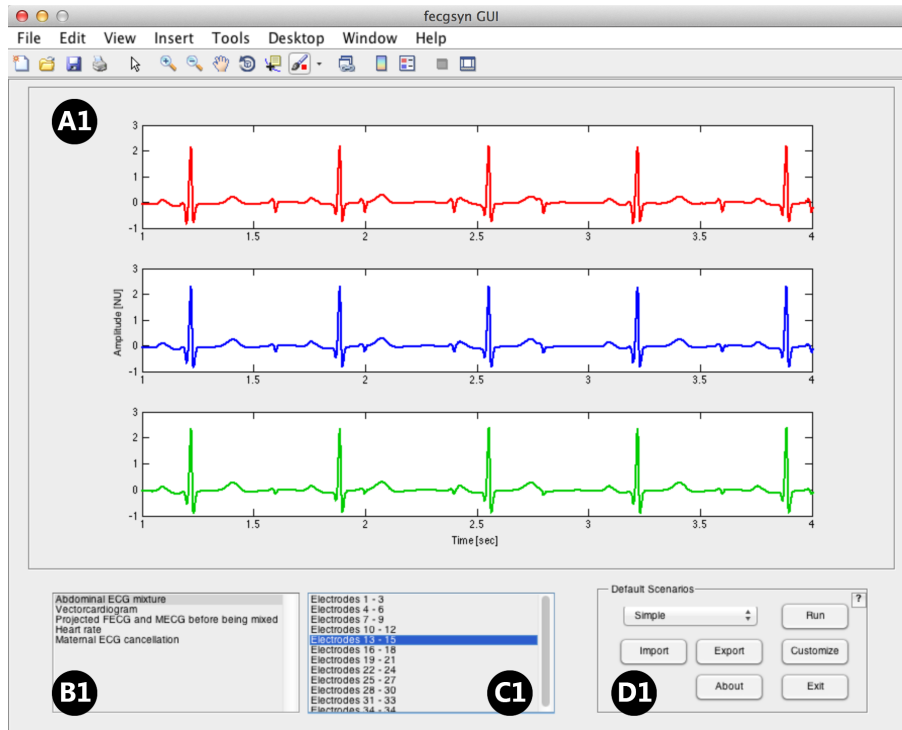
Figure 1. *fecgsyn* GUI - display window. A1: plot display panel of maternal-foetal mixtures for three electrodes, B1: list of visualisation options, C1: subplot list, if multiple plots are available (e.g. for different electrodes), D1, GUI controls.
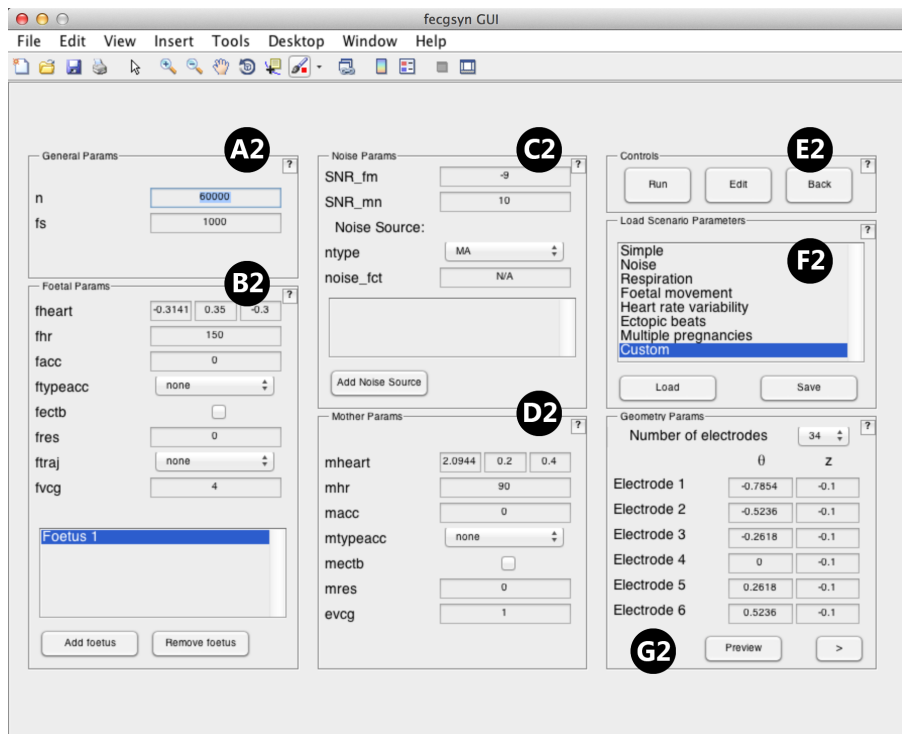

Figure 2. *fecgsyn* GUI - customization window. A2: general signal parameters, B2: foetal parameters, C2: noise parameters, D2: maternal parameters, E2: GUI controls, F2: simulation scenario list, G2: electrode geometry parameters.

3. Predefined scenarios

To facilitate the usage for first-time users, a range of scenarios were predefined in Behar *et al.* [1] to simulate various pathological scenarios and are executable and modifiable from the GUI. The scenarios are:

Simple - a singleton pregnancy with no noise or other pathological activity.

Noise - a stationary noise source is added to the *Simple* simulation.

Respiration - Non-stationary mixing is added through the maternal and foetal respiratory movements.

Foetal movement - introduces helical movement of the foetal heart following some geometric trajectory.

Heart rate variability - introduces maternal and foetal heart rate acceleration.

Ectopic beats - adds ectopic beats for both mother and foetus,

Multiple pregnancies - adds another foetus to simulate the abdominal ECG mixture for twins.

4. Conclusion

This work described the graphical user interface for the *fecgsyn* model [1]. The interface allows the generation of realistic foetal-maternal ECG mixtures with known ground truth in an easily manageable way. The interface can be used for teaching purposes to illustrate the challenges of NI-FECG signal processing in the presence of a variety of non-stationarities. The GUI allows easy access to the underlying *fecgsyn* code and its numerous parameters. The code for *fecgsyn* and the interface described here have been released on Physionet [6] under an open source license. The simulations made possible by the software presented here will provide benchmark data to facilitate stress testing of FECG analysis algorithms in addition to, rather than instead of, real data.

Acknowledgements

References

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