A GENERIC FRAMEWORK FOR THE DEVELOPMENT OF THE SIGNAL SIMULATOR

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Abstract— The EBI measurement method is selected to measure the human thorax or chest region to record EBI datasets for modelling the ICG and IRG signals because impedance is one of the prospective methods in non-invasive methods. Three curve fitting methods polynomial, Fourier series and sum of sines models are evaluated based on the EBI datasets. The evaluation criteria are evaluated in terms of the minimization of the error (SSE), high correlation between data and model (R-Square), as-well-as short execution time. BISS gives the end user the freedom to simulate EBI signals as per his/her needs for further analysis. The simulator imitates the real phenomena of ICG and IRG signals, and thus the EBI simulated signals could be used to evaluate the performance of separation algorithms. The developed EBI simulator (BISS) could be used for teaching and training purposes.

IndexTerms— Electrical Bio-impedance (EBI), Impedance cardiography (ICG), Impedance Respirography (IRG), Bio-Impedance Signal Simulator (BISS).

I. Introduction

In the First step, a human is selected as a Biological system or object. It is divided into three sub-systems, which represent the three main systems of the body, namely the cardiovascular, the respiratory and the muscular systems. Here, the objective is to measure HR, RR, and the ICG and IRG signals from the selected subject. In the second step, the thorax area of the subject was selected as the data source of interest. In this our aim is to select the desired physiological parameters for further use from the full set of physiological parameters, which come from the selected subject area of the thorax.

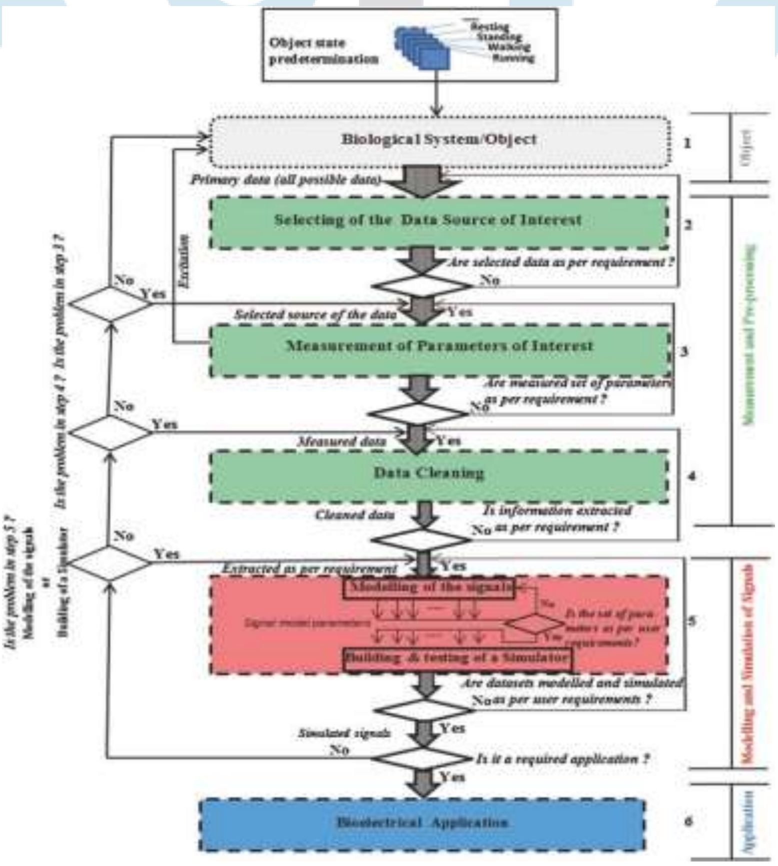

Fig.1: flow diagram of the proposed novel generic framework for modelling and simulation the bioelectrical information.

The physiological parameters of interest are HR and RR. The third step deals with measurement of the ICG and IRG signals, heart rate (HR), and respiration rate (RR) of the human. Thus, the EBI measurement method had been selected. In and this step, the objective is to select the configuration of electrodes and select the type of electrodes. It is decided to use non-invasive EBI measurement method to acquire the EBI data from the subject. In the fourth step is data cleaning on the EBI measured dataset, filtering method was applied to clean the data and attenuate unwanted signals. Then, after cleaning the EBI signal, namely its ICG and IRG signal components are extracted, in the fifth step, the ICG and IRG signals are modelled with the help of one of the three curve fitting methods and the corresponding simulator, namely BISS, is built. The corresponding simulator, namely BISS, is built based on the ICG and IRG signals' modelled parameters. In the sixth, final step, the EBI signals simulator is developed, which has an application to simulate the EBI signal to evaluate the performance of separation algorithms. However, the simulator (BISS) could be used for teaching and training for engineering, health science and medicine students.

II. METHOD FOR MODELLING THE BIO-IMPEDANCE SIGNAL

Here the curve-fitting method is used to model the ICG and IRG signals. Different curve-fitting models are evaluated by comparing the measured and modelled signals based on statistical parameters and visual fit. In the curve-fitting method, three different curve-fitting models are compared, namely polynomial, Fourier series and sum of sines. The comparison criteria were based on visual fit and statistical parameters, namely sum of square error (SSE), correlation between the model and the corresponding dataset fitted modelled values (R-Square), and execution time.

A) Models and Evaluation method

(a) Polynomial Model: Polynomials are well suited in simple empirical model; they can be used for interpolation or extrapolation to characterize data by means of global fit. The general polynomial model formula is given by equation 1,

$$y = \sum_{i=1}^{n+1} p_i t^{n+1-i} \qquad \text{..... (1)}$$

Where n is the degree of the polynomial (highest power of the predictor variable), n+1 is the order of the polynomial (number of coefficients), p_i is the coefficients, and t is time. In this work, the polynomial model was evaluated for degrees 1-9 for the three EBI datasets; degree 9, which is the highest order available in the toolbox, gave the most suitable results.

(b) Fourier Series Model: A Fourier series is a sum of sine and cosine functions that describes a periodic signal. The model formula is given by equation 2,

$$y = a_0 + \sum_{i=1}^{n} (a_i \cos(iwt) + b_i \sin(iwt)) \qquad \text{...... (2)}$$

Where a_0 is the intercept, which is a constant term in the data, w is the fundamental frequency, and n is the number of terms in the series. The model is evaluated with 1-8 terms for the three EBI datasets; the most suitable results were obtained for the degree of eight, the highest available in the toolbox.

(c) Sum of Sines Waves Model: This model consists of a sum of sines terms only. The model formula is given in equation 3,

$$y = \sum_{i=1}^{n} a_i \sin(iwt + c_i) \qquad \text{....... (3)}$$

Where a is the amplitude, w is the frequency, c the phase, which is constant for each term and n is the total term in the series. The model was evaluated with 1-8 terms for the three EBI datasets; 8 terms is the highest available in the toolbox gave the most suitable results.

B) Statistical Parameters

(a) Sum of Squares error: The sum of square error (SSE) statistic assesses the total deviation of the data values from the fitted model, as expressed in equation (4),

$$y = \sum_{i=1}^{n} w_i (y_i - \bar{y}_i)^2 \qquad \text{......... (4)}$$

Where, n is the number of data points, y_i is the response data, and $\bar{y}_i$ is predictor data. SSE values close to 0 indicate that the model is fitted well and has very little random error.

(b) R-Square: The R-Square measure is the square of the correlation between the data and the fitted model values. A value close to one shows a greater correlation between the data and the model, whereas a value close to zero shows a poor correlation. It is determined as the ratio of the sum of squares of the regression (SSR) and the total sum of squares (SST), where SST=SSR+SSE. The R-square measure is given in equation 5,

$$\text{R-square} = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \qquad \text{....... (5)}$$

(c) Execution time: The execution time is measured through Matlab "stopwatch functions (tic, toc)" and reported in the output.

III. PROPOSED BIO-IMPEDANCE SIGNAL SIMULATOR

The bio-impedance signal simulator (BISS) is built based on the three curve fitting models. The simulated EBI signal is generated by summing the ICG signal (S_{ICG}), IRG signal (S_{IRG}), artefacts ($S_{Artefacts}$), and a white Gaussian noise (S_{noise}).

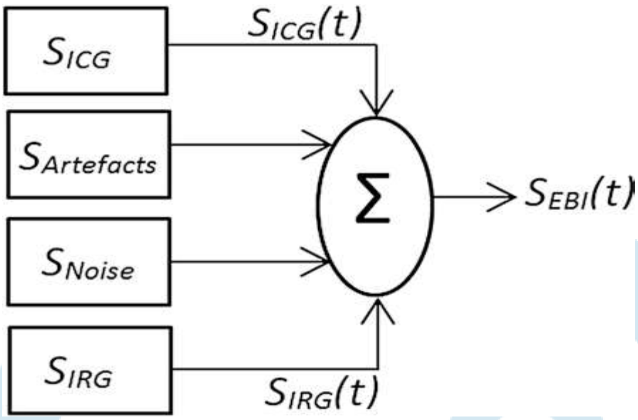

Fig 2: Block diagram of the Bio-Impedance Signal Simulator

In order to make the simple representation of EBI dataset, it is assumed that the EBI data is the summation of the following four components:

$$S_{EBI\,(t)} = S_{ICG\,(t)} + S_{IRG\,(t)} + S_{Artefacts\,(t)} + S_{noise\,(t)}$$

Where, (S_{ICG}) and (S_{IRG}) are the cardiac and respiratory signals, respectively, ($S_{Artefacts}$) is unwanted motion (S_{noise}) is noise. The heart rate of a healthy person can vary in the range between 60 to 240 bpm (1-4 Hz), and the respiration rate of a healthy person can vary from about 12-30 breaths/min (0.2-0.5Hz).

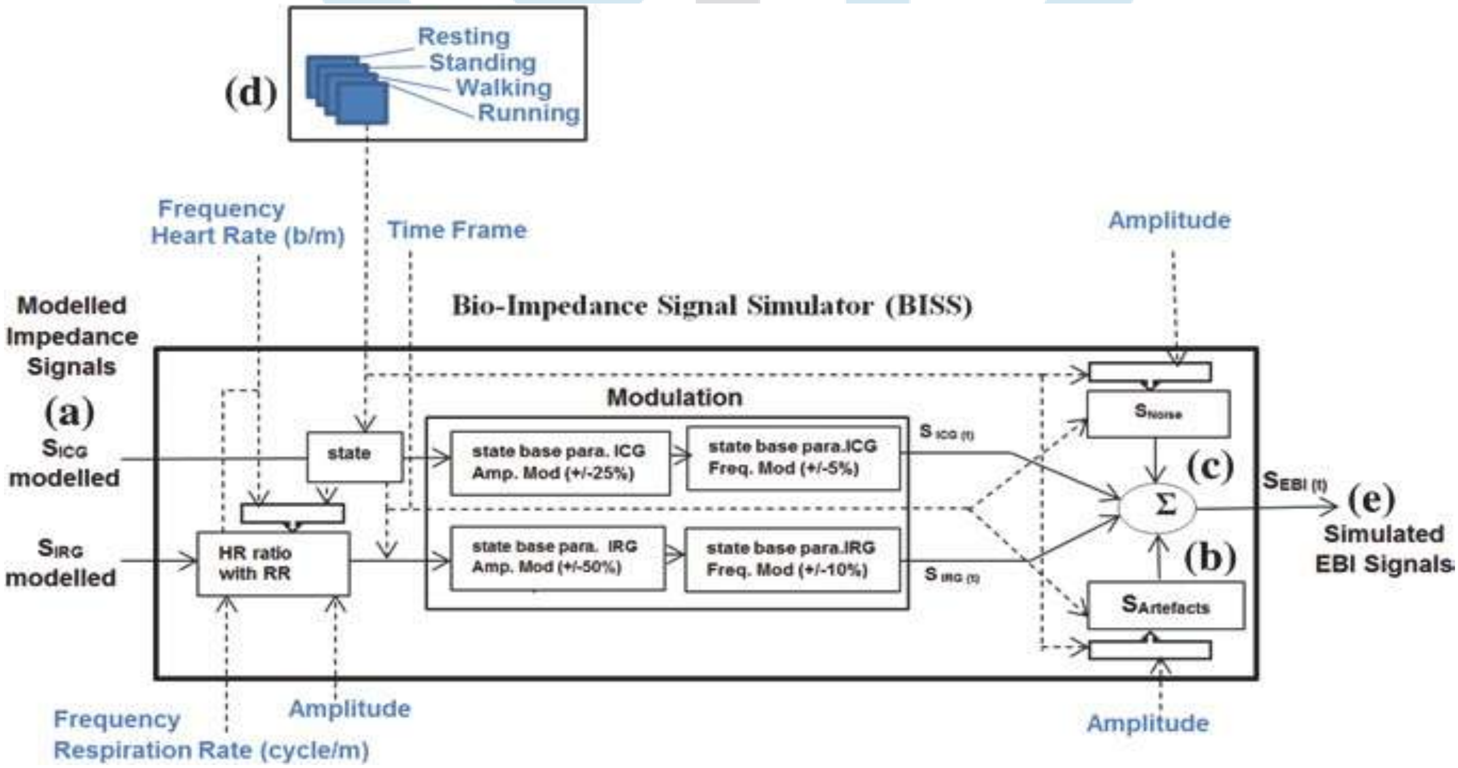

Fig 3: Block diagram of BISS for modelled of the ICG and IRG signals and for development of a corresponding simulator for EBI Signals.

Fig 3 depicts (a) the modelled ICG (S_{ICG}) and IRG (S_{IRG}) signals. (b) recorded motion artefacts ($S_{Artefacts}$) (e.g. swinging arm) added to the simulated EBI signal and (c) a white Gaussian noise (S_{noise}) also added to the simulated EBI signal. The block diagram of the simulator has different pre-recorded states (d) corresponding to a healthy resting, standing, walking, and running persons are included. The end-user also has the possibility to change the parameters as per his/her needs, such as heart rate, respiration rate, timeframe and amplitude of respiration, artefacts and noise. Finally, (e) shows that the simulated EBI signals are mixture of ICG, IRG, artefacts, and noise. The parameters such as heart rate (beats/min), timeframe (sec), respiration rate (cycles/min), amplitude for respiration, artefacts, and noise are controlled by the end-user.

From fig 4, a healthy person's data is loaded. In this figure, the end-user interface of BISS is depicted, including, initially a menu where end- user can load the different states of the person (e.g. healthy rest, healthy standing, healthy walking, and healthy running), open existing simulated EBI signals, save the current simulated EBI signals, and exit the simulator. Then the next part is of the measured and cleaned ICG signal. Then ICG signal modelled by means of the three curve fitting methods. The next we have deal with the IRG signal i.e. measured and cleaned IRG signal and modelled IRG signal by means of three curve fitting methods furthermore, the noise generator, and the recorded artefacts caused by motion (in this example by swinging the arm during the measurement) are come into existence. The output shows the simulated EBI signals model based on the end-user's entered parameters and the detailed summary of simulated EBI signals model and further buttons that let the end-user save the simulated EBI signals.

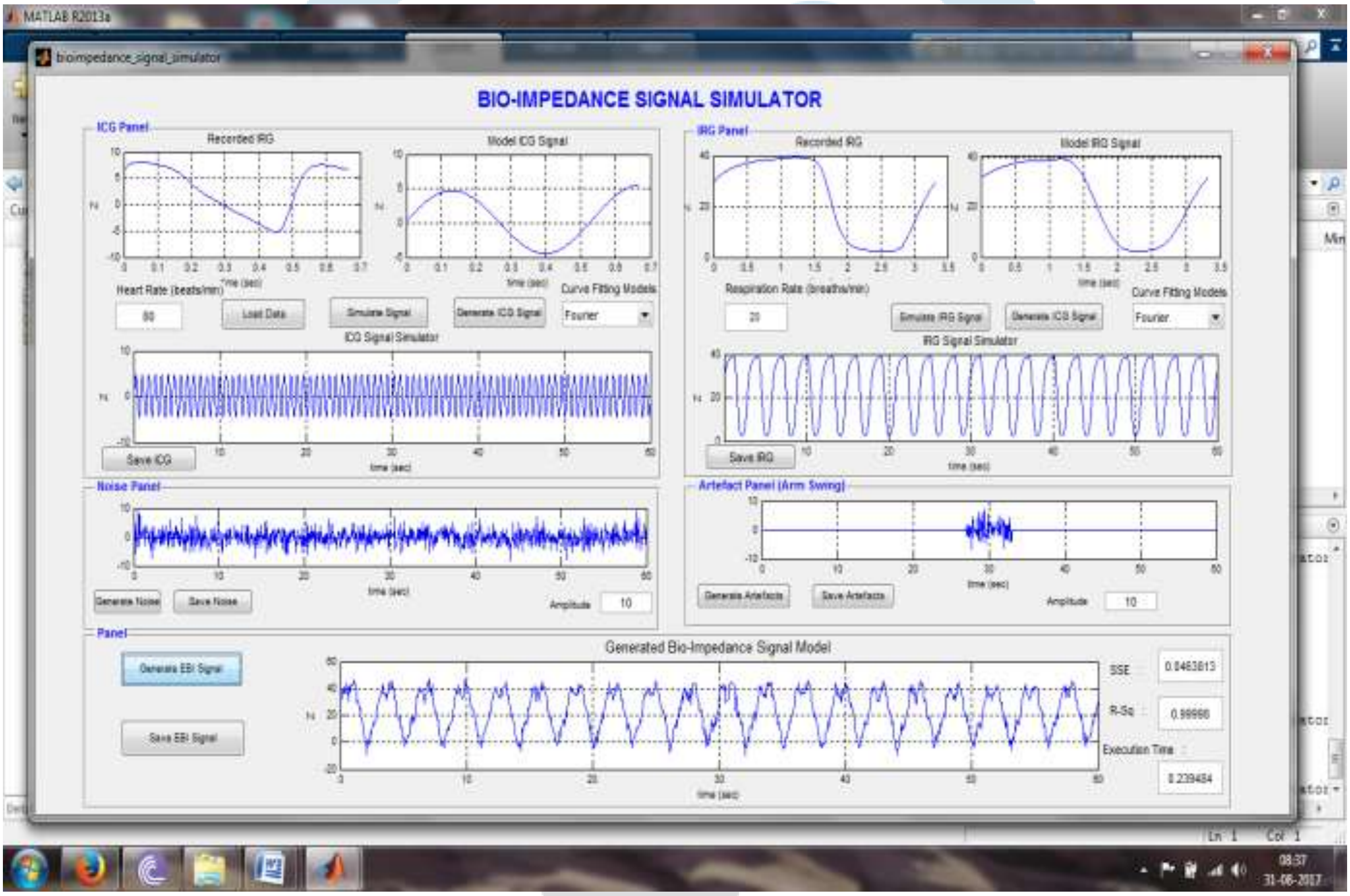

Fig 4 (a): End-user GUI of the BISS simulator based on Fourier curve fitting method.

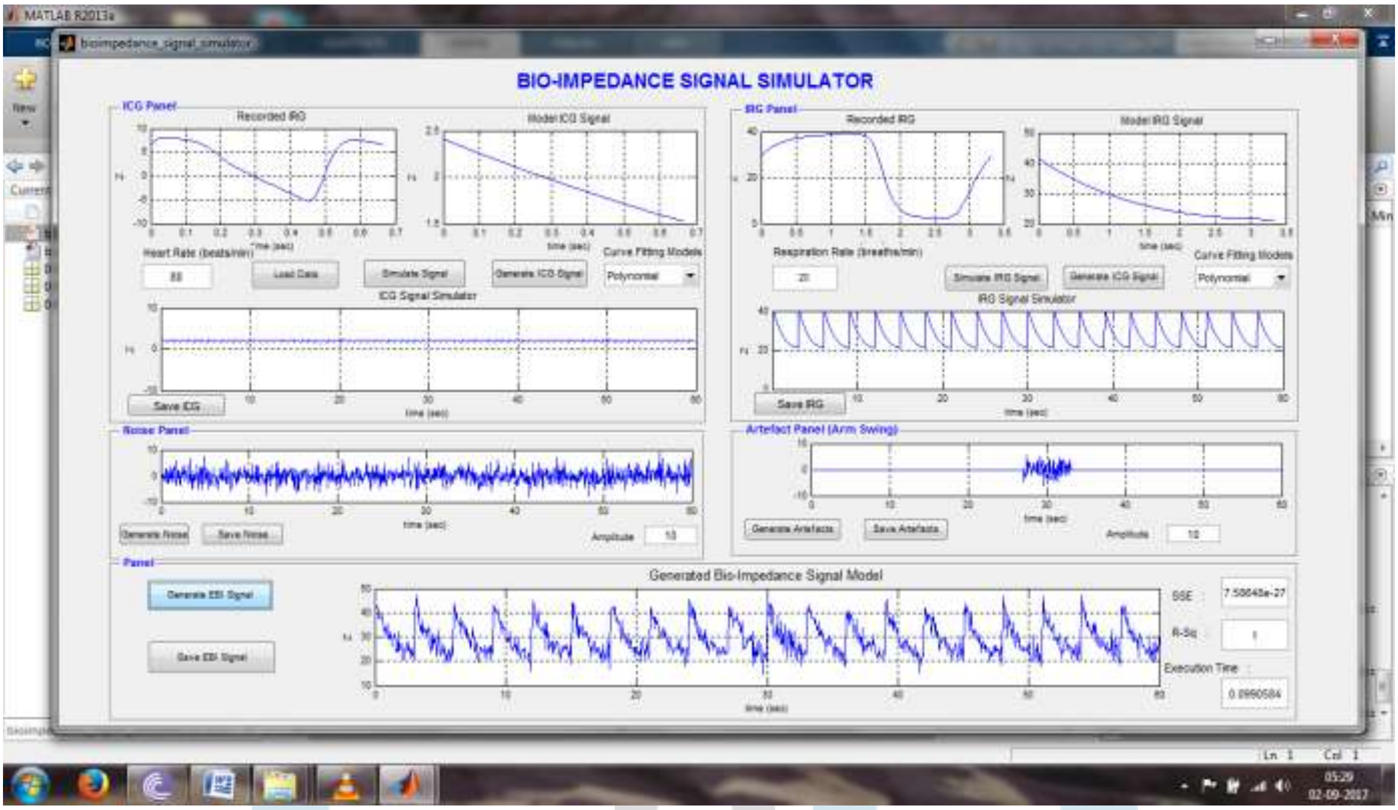

Fig 4 (b): End-user GUI of the BISS simulator based on Polynomial curve fitting method.

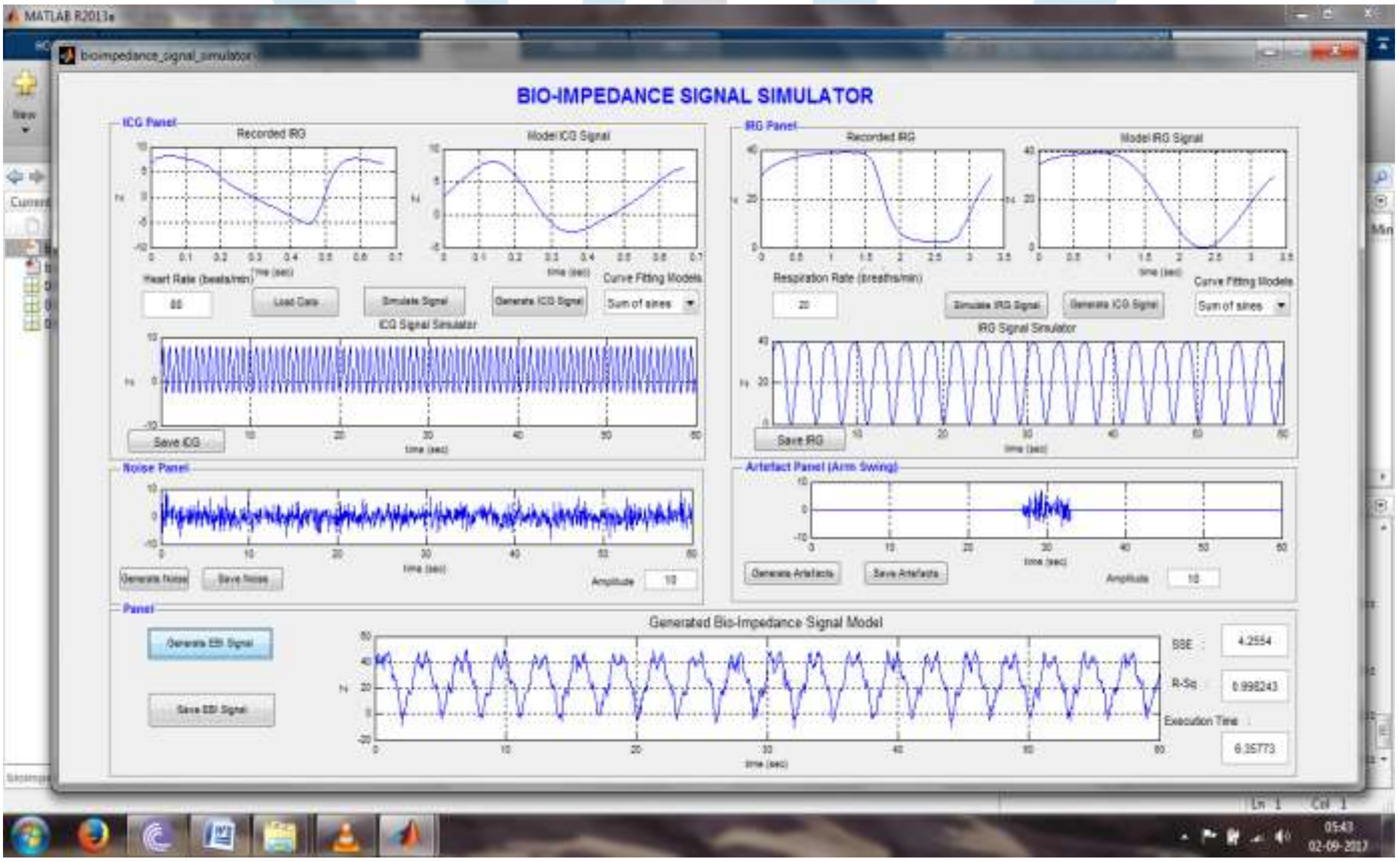

Fig 4 (c): End-user GUI of the BISS simulator based on Sum of sines curve fitting method.

IV. CONCLUSION

Three curve fitting models, namely polynomial, Fourier series and sum of sines models, were evaluated based on EBI datasets. The evaluation criteria were to obtain the best fit both visually and by means of statistical parameters that were evaluated in terms of minimizing of error (SSE), high correlation between the data and the model (R-Square), as well as short execution time. Based on our evaluated results and generally speaking, the three models perform quite well but the Fourier series performed best among them. Building on the Fourier series model, BISS has been developed to simulate the EBI signals. BISS gives the end-user the freedom to simulate the EBI signal as per his/her needs for further analysis. Nevertheless, predefined states are included in BISS. The simulator imitates the real phenomena of ICG and IRG signals, and thus the EBI simulated signals could be used to evaluate and assess the performance of separation algorithms, for example. However, the developed BISS could also be used for teaching and training purposes.

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