# A Bio-Impedance Signal Simulator (BISS) for Research and Training Purposes


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***Abstract*— A Bio-Impedance Signal Simulator (BISS) is developed based on the models of the impedance cardiography (ICG) and impedance respirography (IRG) signals. With the aim of imitating the real ICG and IRG phenomena, the ICG and IRG signals are modelled and combined with motion artefacts and Gaussian noise. The simulator allows the user to load different predefined human activity states such as resting, standing, walking, and running. Moreover, and importantly, the user can also control the parameters as per his/her needs and generate Electrical Bio-Impedance (EBI) datasets for further processing. Possible applications of BISS include research (e.g. performance evaluation of cardiac and respiratory separation algorithms) as well as teaching and training in physiological courses. To the best of our knowledge, BISS is the first EBI signal simulator that imitates the real ICG and IRG signals phenomena.**



***Keywords*— *Biological system modelling; electrical bio-impedance; signal analysis; signal processing algorithms; simulation.***


## I. Introduction

Extraction of useful information from cardiac signals for the diagnosis of diseases and judgment of heart function is of special interest in the medical domain. Thus, the development of effective, robust and efficient diagnostic tools to monitor heart disease symptoms such as cardiac rhythm disorder and arrhythmia is required to help medical personal to investigate and analyze the cardiac signals in details [1], [2].

Among other things, the separation of cardiac and respiratory signals is useful for medical personnel for diagnosing and monitoring purposes. By means of measurement, one can assess physiological activities and the structural configuration of a tissue as well as analyze dynamic processes in organs such as the heart and the lungs. Thus, it is required that a method is developed to separate the useful signals, mainly cardiac and respiratory ones, and to suppress the unwanted components such as noise and motion artefacts from the measured dataset. The method should work robustly and efficiently, ideally in a real time environment.

The research community has developed several algorithms to solve the separation problem, mainly separating the cardiac and respiratory signals from Electrical Bio-Impedance (EBI) [3]-[5], including our previous studies on separation of signals from the EBI measured data [6], [7]. However, none of these methods provide any mechanism to evaluate the performance of the developed separation algorithms.

Because of the measurement and useful signals extraction problem, there exist uncertainties regarding the properties of the signals such as its amplitude, waveform, components (e.g. cardiac vs respiration) and the origin of the signal waveform (e.g. is it due to configuration/positioning of electrodes/sensors or the condition of the patient), which in turn, limits the quality of the diagnosis of diseases and conditions. Thus, modelling the ICG and IRG signals can increase the confidence level when applying signal-processing algorithms onto real measured EBI data.

## II. Modelling the Cardiac and Respiratory Signals

The modelling of the cardiac and respiratory signals allows the advance of knowledge regarding the interplay of anatomical structures and physical phenomena, which contribute to cardiac and respiratory physiological and pathophysiological behaviors. Applications of this knowledge are found in biomedical research. An important application thereof is to evaluate the performance of e.g. separation algorithms. The signal model provides a simplified description of the heart and lungs activities and can exist in a physical and mathematical representation.

The ICG and IRG signals have to be modelled and the corresponding simulator has to be developed in such a way so that the user can use the simulator to generate EBI datasets as per his/her needs. It can be argued that modelling the measured signals offers several advantages as compared to using measured data only:

a) By using a formalized representation (e.g. mathematical), the parameters of the signal model can be easily manipulated and/or modified, thus providing mechanisms that allows researchers/users to reproduce and control such signals.

b) In turn, having such a formalized signal model makes it possible to develop tools (e.g. simulators) that can be used for manipulating and understanding how the signal changes depending on various conditions, as well as for generating input data for experimenting with and evaluating the performance of e.g. useful signals extraction methods such as separation algorithms.

Our previous results [6]–[8] motivated us to develop a signal model that imitates the real phenomena of the cardiac and respiratory signals. In addition, the user has the freedom to generate simulated data based on his/her needs and mix-in artificial artefacts and noise to represent real-life measurement issues.

Based on our previous work [8], it is assumed that existing thorax models do not fit our requirements for developing bio-impedance signal models and that such models should instead be derived from real measured data.

Thus, three mathematical models, namely polynomial, sum of sines and Fourier series, were compared based on statistical parameters (sum square error (SSE), correlation (R-Sq) and execution time). It was concluded that the Fourier series is the best among these three methods to model the ICG and IRG signals [9], [10].

## III. DEVELOPMENT OF THE SIMULATOR

The simulator for the ICG and IRG signals has been developed; in this section, we first discuss a generic approach to develop the simulator and then present the specific implementation of the bio-impedance signal simulator (BISS).

### *A. Generic approach to develop the simulator*

The generic approach to develop the simulator is depicted in Figure 1. The information to be modelled is based on the extracted information; such a model should imitate the real phenomena. Furthermore, the simulator should be user friendly and provide facilities to the user for controlling different kinds of parameters.

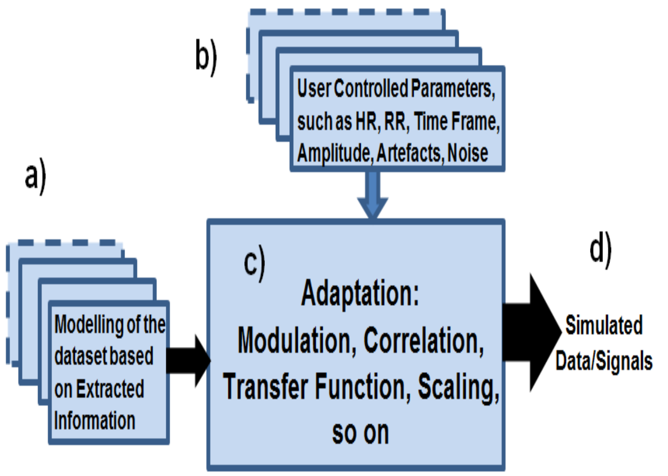


Fig. 1. Block diagram of the generic approach to develop the signal simulator

Figure. 1 shows that a) the information can be modelled with different approaches, b) the user-controlled parameters which give the user freedom to control and simulate the artificial dataset based on his/her needs, c) the internal mechanism of the simulator that imitates the real phenomena of the extracted information, and d) the generated simulated data/signals.

Once the developed signal model has been validated against template signals, and can thus imitate the real phenomena, it means that the original values of the signal model parameters are set. These values will only be modified, in the simulator, by the user.

Next, it is required to build the corresponding simulator where the predefined signal model parameters are also possibly controlled (i.e. overwritten) by the user. Moreover, other parameters (internal to the adaptation process) could also be introduced in the simulator by the user; these can also be possibly controlled by the user. These other parameters are used inside the adaptation process to tune the signal model parameters in order to reflect the actual phenomena that take place in the biological system/object of interest.

The core mechanisms of the simulator include adaptation; either the adaptation of the signal model is done according to the user's need/requirement or his/her desire to simulate the signals. The generator block inside the adaptation process generates the simulated signals as per user prescribed parameters. Therefore, the user is able to control the signal model parameters and generate the simulated signals as desired.

### *B. Specific approach to develop the Bio-Impedance Signal Simulator (BISS)*

The development of the specific bio-impedance signal model simulator is motivated by the desire to simulate the EBI signal so as to evaluate the performance of signal processing algorithms such as cardiac and respiratory separation algorithms.

To simplify the representation of EBI dataset, it is assumed that the EBI data is the summation of the following four components:

$$S_{EBI(t)} = S_{ICG}(t) + S_{IRG}(t) + S_{Artefact}(t) + S_{Noise}(t), \quad (1)$$

where $S_{ICG}(t)$ and $S_{IRG}(t)$ are the cardiac and respiratory signals, respectively, $S_{Artefact}(t)$ is unwanted motion artefact caused by body movements or muscle activity and $S_{Noise}(t)$ is noise [10].

The simulator is depicted in Figure 2, where the simulated EBI data is generated by summing the signals $S_{ICG}(t)$, $S_{IRG}(t)$, $S_{Artefacts}(t)$ and $S_{Noise}(t)$.

The heart rate $S_{ICG}$ (Eq. 1) of a healthy person can vary in the range 60 bpm to 240 bpm (1 to 4 Hz); the respiration rate $S_{IRG}$ (Eq. 1) of a healthy person can vary from about 12 breaths/min to 30 breaths/min (0.2 to 0.5 Hz) [6].

Figure. 2 shows a) the modelled ICG and IRG signals, b) recorded motion artefacts (e.g. swinging arm) added to the generated signals, and c) Gaussian noise also added to the generated signals.

In BISS, different pre-recorded states d) corresponding to a healthy resting, healthy standing, healthy walking and healthy running persons are included. Each state has different parametric values and cardiac relationship with respiration, which vary depending on each state/condition.

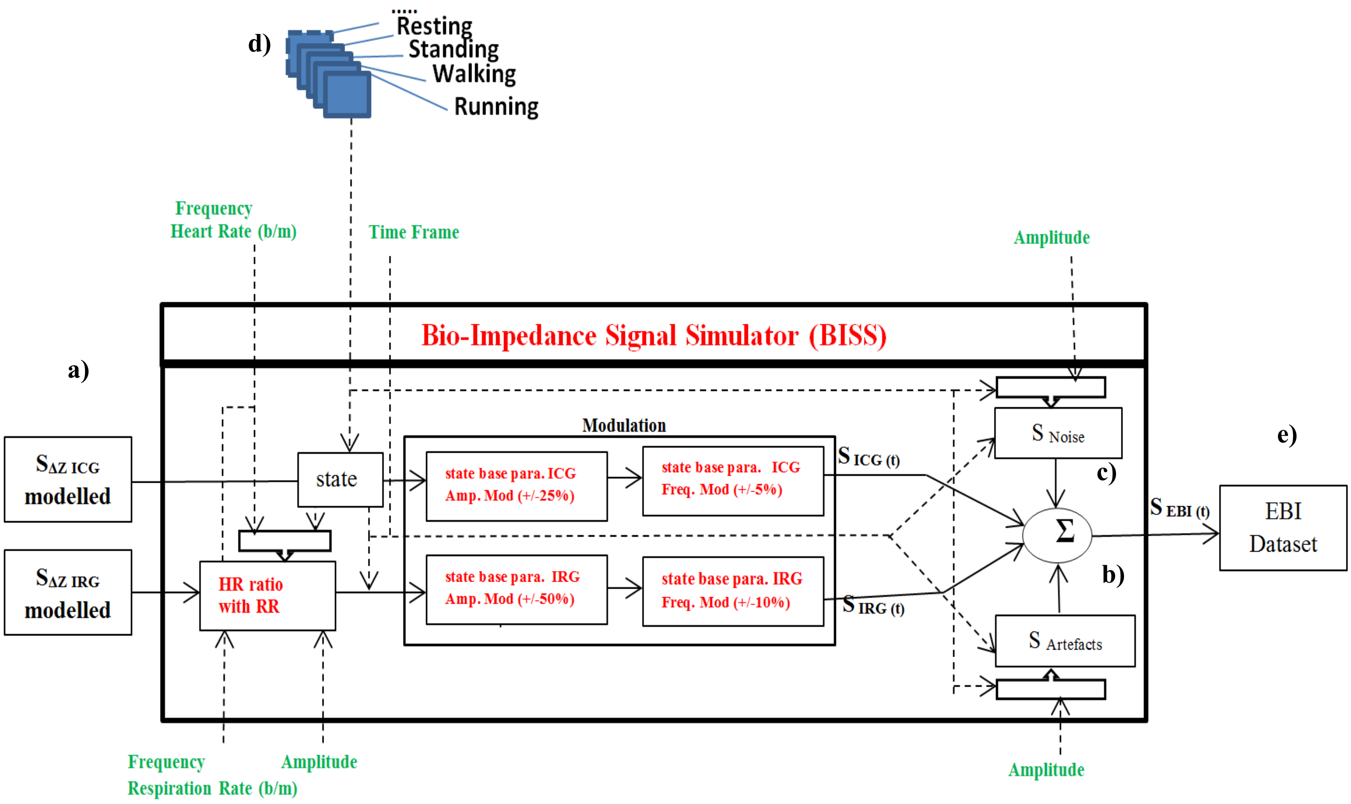


Fig. 2. Specific block diagram of BISS for modelling of the ICG and IRG signals and for development of a corresponding simulator for EBI Signal

Nevertheless, the user has also the possibility to change the parameters as per his/her needs such as heart rate, respiration rate, time frame, and amplitude of respiration, artefacts and noise. Finally, e) shows that the generated EBI dataset is a mixture of ICG, IRG, motion artefacts and noise. Such a dataset can then be used for further processing (e.g. to evaluate the performance of separation algorithms).

In Figure. 2, it is shown that the outer parameters such as heart rate (beats/minute), time frame (sec), respiration rate (cycles/minute), amplitude for respiration, artefacts and noise are controlled by the user (possibly overriding the values loaded from a pre-recorded state).

The cardiac amplitude (Figure. 3 (f)) in BISS is based on systolic and diastolic activities in order to imitate the real phenomena of the heart. If the heart rate increases, the amplitude of ICG decreases and the diastole period also decreases. If the heart rate decreases, the amplitude of ICG increases and the diastole period also increases. A small variation is also introduced in systolic activities as per cardiovascular phenomena.

In order to imitate the real phenomena, signal modulation is included in BISS. The ICG amplitude modulation is ±25% and frequency modulation is ±5%, depending on the heart rate. This makes cycles different from each other. Similarly, modulation is also introduced for respiration (IRG) amplitude (±50%) and frequency (±10%). Medical doctors confirmed these modulation ranges.

## IV. RESULTS

Figure. 3 shows the user interface of BISS, including a) a menu where the user can load the different states of a person (e.g. healthy rest, healthy standing, healthy walking and healthy running), open existing EBI datasets, save the current EBI dataset and exit from the simulator. The model parameters can also be directly configured by the user.

In Figure. 3, the profile of a healthy running person is loaded, b) is the measured and cleaned ICG signal, c) is the modelled ICG signal by means of Fourier series method [9], d) is the measured and cleaned IRG signal, e) is the modelled IRG signal by means of Fourier series method [9], f) is the continuously moving and simulated ICG signal where modulation is introduced with each cycle in amplitude and frequency, and g) is the continuously moving and simulated IRG signal where modulation is introduced with each cycle.

The respiration rate is correlated to the cardiac heart rate by means of a ratio. The default ratio is 5:1 (5 cardiac cycles for 1 respiration cycle). Nevertheless, the user can also control the respiration rate.

Furthermore, h) is the noise generator, i) the recorded artefacts caused by swinging the arm during the measurement (randomly moving in the defined time window), j) the generated EBI signal model based on the user entered parameters, k) the detailed summary of the generated bio-

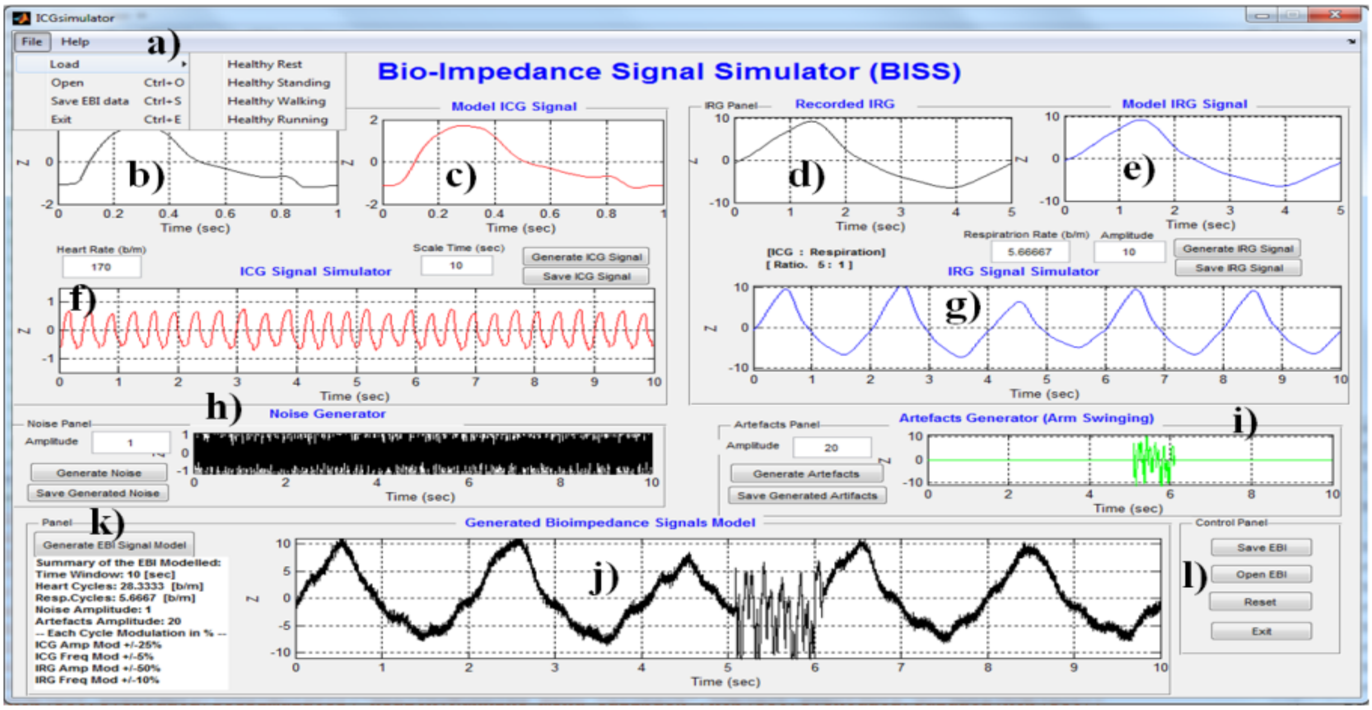


Fig. 3. BISS simulator's user interface with the signals simulated for the state "healthy person during running"

impedance signal model, and l) buttons that let the user save the EBI signal mode, open existing EBI dataset, clear all simulated model signals and start again and exit from BISS' GUI environment. It can clearly be seen from Figure 3 that the generated EBI signals are different due to the selected running states, noise level, artefacts amplitude and location, and ICG and IRG modulations.

## V. CONCLUSION

The proposed novel BISS signal simulator implements the developed signal models and imitates the phenomena of systolic and diastolic activities of the cardiac and the respiration mechanisms. BISS also gives the freedom to the user to simulate EBI signals as per his/her needs. BISS can be a useful tool to simulate the EBI datasets in order to evaluate the performance of signal processing algorithms, e.g. for the separation of cardiac and respiratory signals. Thus, the proposed approach can increase the confidence level when applying developed algorithms on real measured EBI data. Moreover, BISS could also be used for teaching and training in physiological courses targeted at engineering and health science students as it can give hands-on means to the students to understand the complicated physiological phenomena.

## ACKNOWLEDGMENT

The authors thank Prof. T. Rang, Prof. M. Min, Dr. T. Parve and Dr. M. Naveed for providing valuable advice. This research is supported by the EU through the European Regional Development Fund in frames of the research centre CEBE, the competence centre ELIKO, the Estonian Ministry of Education and Research under research grants ETF8592 and IUT19-11, the ESF DoRa grant and the IT Doctoral School for supporting the Tech. oriented scientific projects in Estonia.

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