NONSTATIONARY BLOOD FLOW / WALL MOVEMENT ESTIMATOR USING DOPPLER ULTRASOUND

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Abstract: Doppler instruments are used as a non invasive technique to diagnose vascular disease. Since arterial wall, surrounding moving tissue and red blood cells (RBC) all contribute to the collected signal, assessing the bloodstream characteristics accurately requires the separation of this components from the ones arising from the RBCs. The wall component is characterized by high amplitude and low frequency. So, the conventional method of achieving signal discrimination is to apply a high-pass filter to remove all low frequency signals below a certain cut-off frequency (typically 200Hz for a 5MHz Doppler instrument). This procedure cancels the unwanted wall signal. Unfortunately, also eliminates the information arising from the slowly moving RBCs, which constitutes a major drawback in accomplishing precise blood flow characterization and limits the instrument's use in early detection in vascular disease. Several techniques have been proposed to improve blood flow estimation; in this paper we describe a toolbox that allows the automatic comparison of any new proposed method against the conventional methods. It also allows the optimisation of the proposed method using simulated Doppler signals.

Introduction

Conventional spectral analysis of the Doppler signal is performed using the STFT. To study new methods for Doppler signal analysis simulated Doppler signal with known characteristics must be used. The models for the Doppler signal indicate that for undisturbed flow it is random, with a Gaussian Probability Density Function (PDF) and a spectral width determined by the range of magnitudes of blood red cells velocities passing through the sample volume.

The nonstationary signal may be written [1] as

$$x_D(t) = A(t)e^{j\Phi_r(t)}e^{j\Phi_D(t)} \quad (1)$$

where $A(t)e^{j\Phi_r(t)}$ is a random base-band function, and $e^{j\Phi_D(t)}$ is a frequency shifting function with an instantaneous frequency equal to the spectral center frequency waveform $f_i(t)$. The wall signal is generate from the pressure signal. It is assumed that the wall displacement is proportional to the pressure [2].

The results presented in this work to separate the blood flow signal from the artery wall movement clutter were obtained using a method that estimates first the spectrogram for each cardiac cycle and passes it through an averaging filter of order 10*10. A threshold is then established to detect the wall thump signal, the spectrogram is equated to zero at the wall signal time-frequency positions before the mean frequency being estimated.

In our simulation the mean frequency was varied during the cardiac cycle. The bandwidth was kept constant at 800 Hz (rms). The clutter to blood signal ratio used was 40 dB.

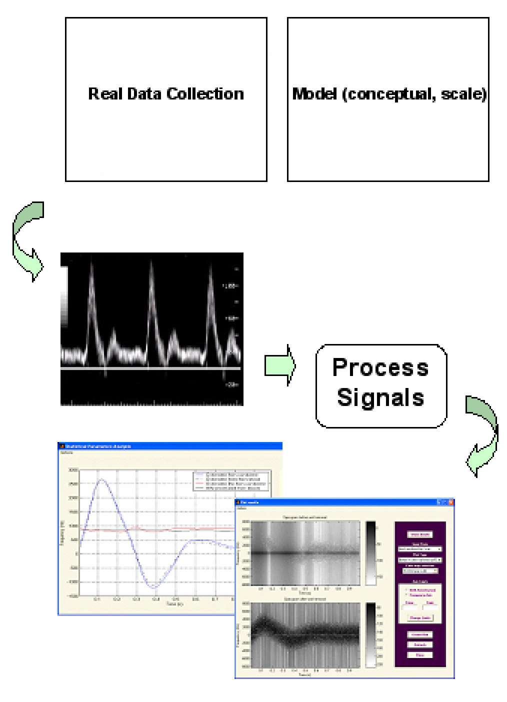

Figure 1: Doppler signal processing acquisition / simulation, display and analysis

We have developed a toolbox, using Matlab, that allows the computation of the characteristics of Doppler signals, instantaneous mean frequency and bandwidth, figure 1, using several methods. Results for each

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method are automatically compared with the results obtained with other methods. For each method, it is also possible to optimise the parameters to minimize the bias and variance of the estimation. To do this it is used a database of simulated Doppler signals.

Materials and Methods

A toolbox with a Graphic User Interface (GUI) was developed to help researchers to compare results from different Doppler spectral estimator methods against the same database of signals with known characteristics. It is also possible to increase the database signal pool simulating new signals with the desired Doppler signal characteristics, namely, mean frequency waveform, bandwidth, blood / clutter ratio, signal / noise ratio, etc. When a new set of signals is simulated the system may generate the output results for the various spectral estimation methods already implemented in the toolbox.

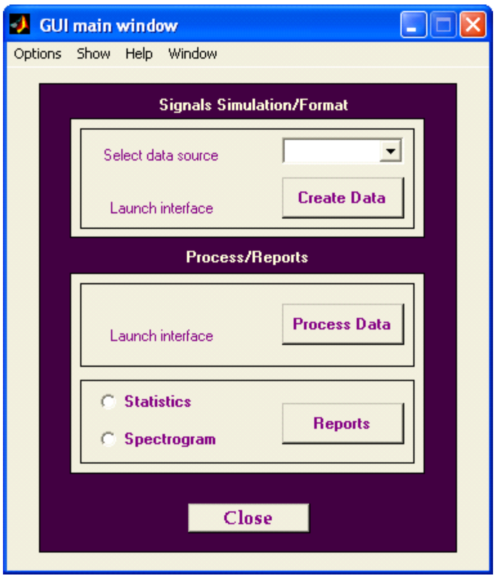

Figure 2: Graphic User Interface main window

Already implemented and functional are some techniques that represent an alternative to the traditionally used methods for achieving signal discrimination. Other functionalities were included and organized in several sub windows, all of which controllable from the GUI main window presented in figure 2., creating a friendly development environment for the user and assuring that all the methods are compared against the same set of signals so that the results of the spectral estimation methods may be compared.

An important aspect of this tool is its capability to handle information. In order to fulfil the needs it becomes necessary to be able to retain and reuse information at any given time. This brought out the need to ensure access to the previously obtained information and to do so in an orderly way. With that purpose, a data file structure was developed in order to withhold the results produced during the signals creation process (simulation or real data acquisition).

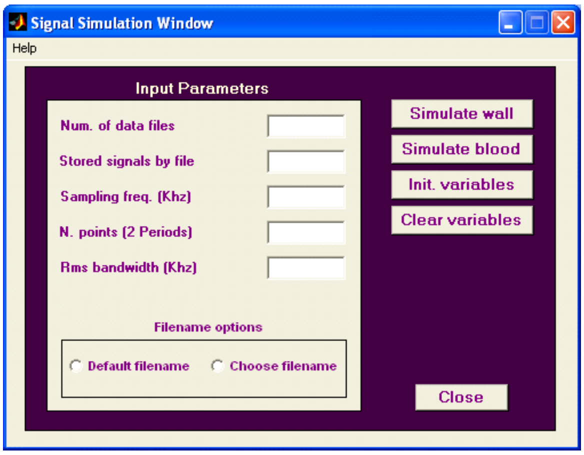

Figure 3: Signal simulation window

Three types of information were saved for each simulation: general data (number of signals stored, date and time); specific data of the simulation model (sampling frequency and number of samples for each signal); and the signals themselves.

Figure 4 shows de structure implemented in the data files. In each one of them exists a variable that branches into three fields, where the data will be placed accordingly to the description made before. Although the explanation was made considering the unprocessed data, this also applies to the processed signal samples because a similar procedure was used.

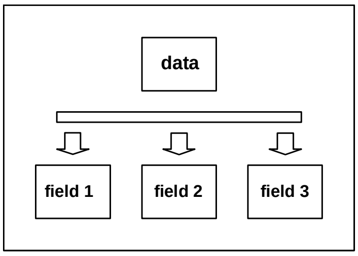

Figure 4: Data file organization

The database directory tree, where files are kept, is dynamic. This means that it is possible to rearrange its structure in order to suit one's needs. For that, exists in the interface a directory browser, which is useful to organize and change the database whenever necessary.

This toolbox enables the researcher to use real data, acquired with the aid of ultrasonic equipment. The collected signal samples, *in vivo* or *in vitro*, must be stored in "wave" or "text" formats, so that they may be easily converted to a compatible data format. That task is accomplished in the menu displayed in figure 5.

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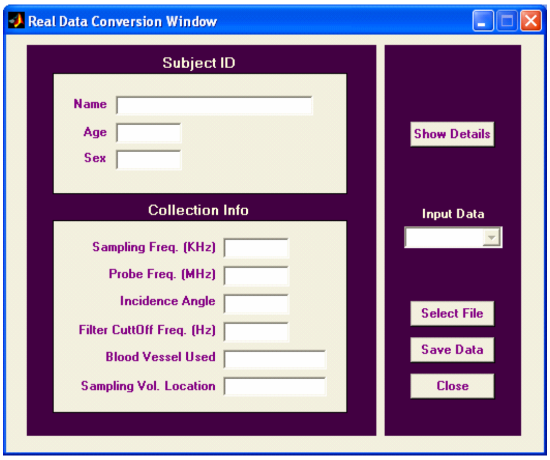

Figure 5: Data conversion window

When formatting the information the user has the possibility to characterize the data. For example, suppose the collection was obtained *in vivo*. It is possible to insert the name, age, gender or even store information regarding the equipment used, probe frequency and sampling frequency. All of that will be saved in a file along with the extracted signals. This permits, at all times, to cross-reference and check the information contained in the database and helps to prevent the presence of superfluous data.

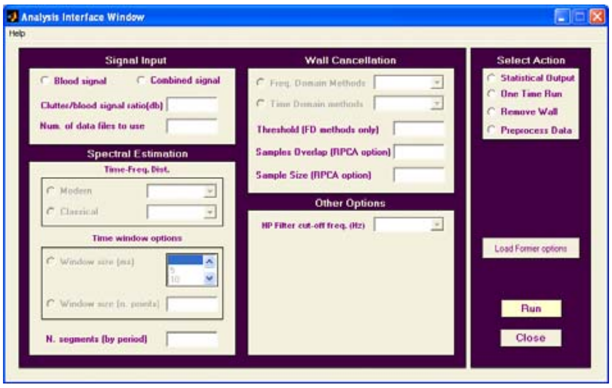

Figure 6: GUI processing window

Once the data files are in place, everything is ready to start processing. At user criteria are a collection of time-frequency distributions, clutter cancellation methods and other auxiliary functions that will provide for research or clinic users the opportunity to develop, test and improve their algorithms.

The user may choose between two kinds of outputs. One, gives access to a set of statistical parameters computed during the test run, correspondent to the signal processing technique applied, that latter on may serve as a base of comparison for testing other methods. Another study approach enables to view the Time-Frequency representation of the data before and after being subjected to manipulation. By immediate analysis of both plots, it is possible to assess results.

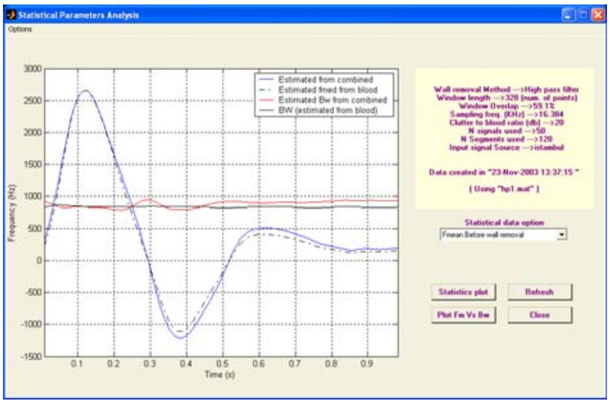

Figure 7: Report window, statistics analysis

After processing, the resultant information is saved, and can be accessed at any time thought the report windows available. Figure 7 shows an example of a comparative graphic of mean frequency and bandwidth waveforms, obtained from simulated Doppler signals.

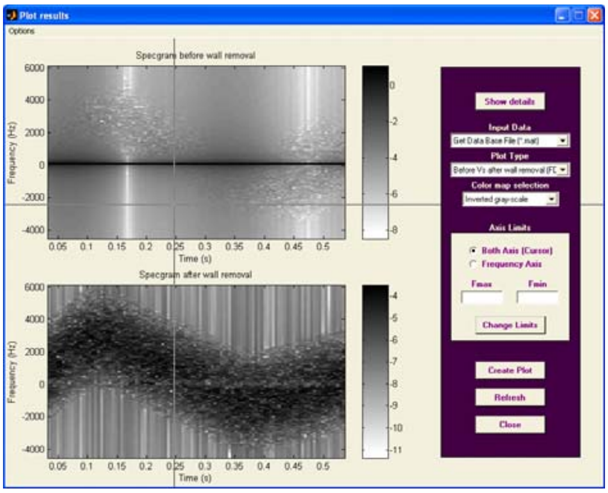

Figure 8: Time-Frequency representation. a) wall clutter; b) blood flow with wall clutter removed

Results

The studies described in this work focused on the use of non-linear processing on the unfiltered Doppler signal spectrogram to remove the wall component. [2] The characteristic low frequency/high amplitude and short duration wall signal is detected in the time-frequency plot and removed, resulting in loss of low frequency information during part of the cardiac cycle when the concentration of power is predominantly around 0 Hz.

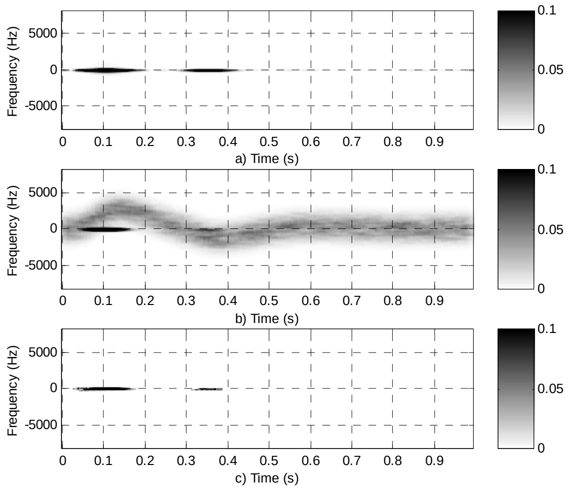

Figure 9: Spectrogram of the (a) wall signal; (b) Doppler and clutter signal after average filter (c) signal removed with smooth and threshold method

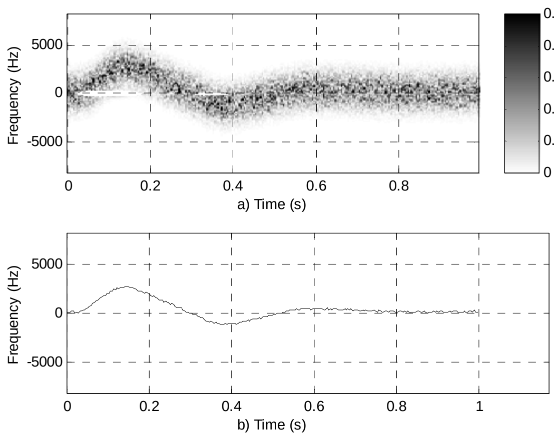

Figure 10: a) Spectrogram of the Doppler signal with wall clutter adaptive filtered; b) Mean frequency estimation of Doppler signal with wall clutter signal eliminated

Figure 9-a) shows the spectrogram of the simulated wall signal that was added to the simulated blood Doppler signal, Figure 9-b) shows the spectrogram of the simulated Doppler and wall signal after the averaging filter and Figure 9-c) shows one example of the spectrogram of the removed signal. The wall thump signal removed varies highly with the threshold used, in this example has used 0.07 for 40dB clutter to blood signal ratio.

The Doppler signal mean frequency estimations were averaged over 100 cardiac cycles, for all cases under analysis. Figure 10 shows the Doppler signal spectrogram with wall clutter filtered in the time–frequency plan. Figure 10-b) shows the mean frequency waveform estimated.

The error in the estimation of the Doppler mean frequency depends on the threshold value used and the maximum frequency considered for wall movements. The threshold value relates the power between clutter and blood signals. Its value should change also with the clutter to blood signal ratio.

Conclusions

The toolbox described here with a friendly user interface, presents it self as a potentially valuable tool because it may help research between different research groups since it allows the comparison of results against the same database of simulated signals and/or real data. One of its characteristics is modularity, which allows for new methods of Doppler signal analysis to be easily added. In addition, it's possible to quickly compare results between different methods, which are already in the database.

References

[1] WANG Y., and FISH P.J. (1996): 'Arterial Doppler signal simulation by time domain processing', Eur. J. Ultrasound, vol. 3, pp. 71-81

[2] CARDOSO J.C:, FISH P.J., and BASTOS C.A.C. (2002): 'Improved blood/wall signal separation in Doppler ultrasound', Proc. ICBME 2002: "The Bio-Era: New Challenges, New Frontiers", Singapore, 4-7 December 2002

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