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A Biomedical Signal Processing Toolbox

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Abstract. This paper describes a biomedical signal processing (BSP) toolbox for the analysis of physiologic signals. The BSP toolbox is designed to enable researchers to conduct preliminary analysis of physiologic time series, such as the electrocardiogram (ECG), intracranial pressure (ICP), arterial blood pressure (ABP), and oxygen saturation (SpO_2). The toolbox includes detection algorithms for the ECG and pressure waveforms, spectral analysis, nonlinear filtering, multi-signal analysis, and nonstationary signal visualization. The following sections discuss the functionality of this toolbox and provide examples of its application.

1 Introduction

As the cost of computation continues to decrease, biomedical signal processing algorithms are becoming more sophisticated. Most of these algorithms are designed to extract information from signals that is not apparent from visual inspection of the signal alone. Developers of these algorithms rely largely on proven methods of time series analysis and signal processing to serve as building blocks for these advanced algorithms. We suggest that biomedical signal processing algorithms require additional tools that address the unique nature of physiologic signals such as nonstationarities, event detection, and large-amplitude disturbances.

We have designed a BSP toolbox that enables algorithm developers and applied researchers to conduct preliminary research and extract fundamental features from physiologic signals. The toolbox includes QRS complex detection, pressure signal component detection, spectral analysis, multi-signal analysis, nonlinear filtering and non-stationary signal visualization. This MATLAB based toolbox complements the functionality of other software packages such as those available from *PhysioToolkit*, an online library of software for physiologic signal processing and analysis, interactive signal display, and database creation [1]. The purpose of this paper is to describe the functionality of the BSP toolbox and to provide examples of how it may be used to extract information from physiologic signals.

2 Methodology

The BSP toolbox was developed using both current signal processing techniques and newly developed algorithms. The toolbox was implemented in MATLAB because of its widespread use among engineers, its extensive library of intrinsic functions that enable rapid prototyping, the visualization capabilities, and the portability between platforms. Each function in the toolbox is fully documented and includes keywords, a description of the algorithm, input and output arguments, default values, an example, and references.

3 Description

The functions implemented as part of the BSP toolbox were divided into the following categories: detection algorithms, spectral analysis, nonlinear filtering, multi-signal analysis, and nonstationary signal visualization tools. Fig. 1 illustrates the toolbox architecture.

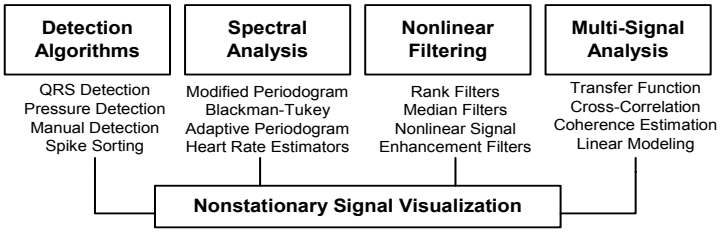

Fig 1. Diagram of the BSP toolbox architecture

3.1 Detection algorithms

The toolbox includes beat-to-beat detection algorithms that also extract specific features from each beat. This includes an automatic algorithm for the detection of beat components within pressure signals (e.g. ABP, ICP, and SpO_2) and a QRS detection algorithm for the ECG [2]. The algorithm provides information about the temporal location of the different beat components. The feature extraction function uses the detected components and calculates the interbeat intervals, slopes, relative beat amplitudes, and the beat morphology (see Fig. 2).

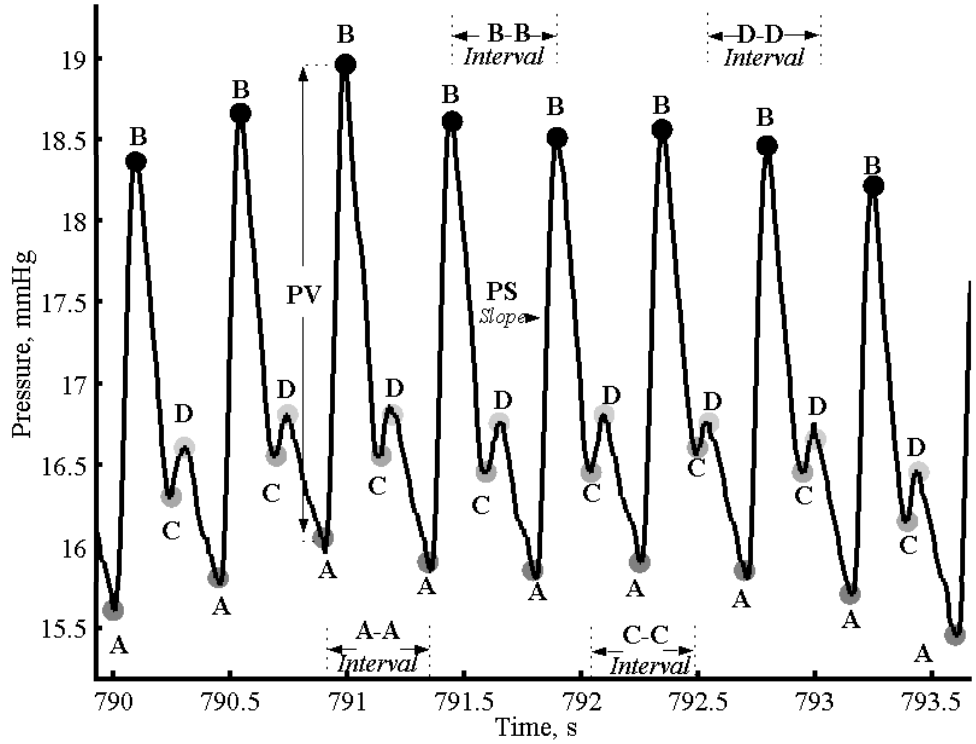

Fig 2. Example of beat component detection from an ICP signal using the pressure detection algorithm included in the BSP Toolbox. The figure illustrates the detection of the percussion peak (B), dichrotic notch (C), and dichrotic peak (D).

3.2 Spectral Analysis

Spectral analysis methods include a modified periodogram, Blackman-Tukey methods for spectral estimation, data-adaptive spectral estimation tools, and heart rate estimators. This set of routines is used to extract information from a given time series about its power spectral density, heart rate variability, and signal decomposition.

3.3 Nonlinear Filtering

Nonlinear filters include rank order filters, edge-preserving filters, and lowpass filters that preserve peak amplitudes [3]. These filters are used for signal enhancement and correction of problems such as movement artifact and quantization noise.

3.4 Multi-signal Analysis

Four standard techniques for estimating the relationship between two signals are included in the toolbox: linear modeling, transfer function estimation, coherence analysis, cross-spectrum estimation, and cross-correlation estimation. Fig. 3 shows an example of the cross-correlation estimation function.

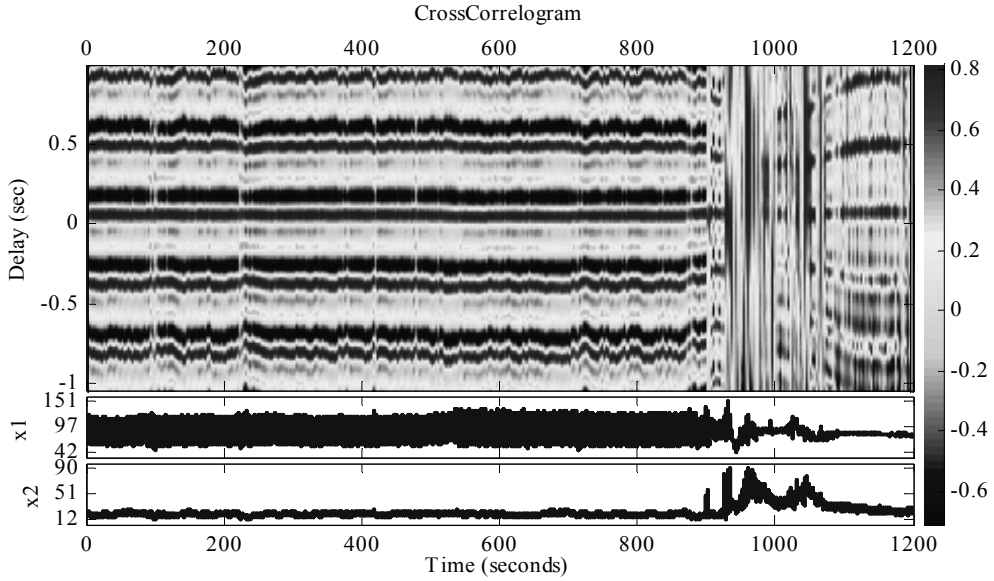

Fig 3. Example of the cross-correlation visualization function. The function estimates the cross-crorrelation between a pair of signals versus time. This example shows the cross-correlogram of an ABP and ICP pair. The top plot shows the change of cross-correlation over time. The middle plot shows the ABP time series. C) The bottom plot shows the ICP time series.

In this figure, the two plots at the bottom show a pair of signals (ABP and ICP) simultaneously recorded from a pediatric intensive care unit patient. The top plot shows the cross-correlation between the two signals for different delays and how it progresses over time. This visualization tool allows us to see how a specific event alters the correlation between the signals. In this example, the ABP and ICP signals are highly correlated, except during the brief episode of intracranial hypertension, where the signals appear highly uncorrelated.

3.5 Nonstationary Signal Visualization

Tools for visualization of nonstationary biomedical signals include common techniques such as spectrograms and scaleograms and new techniques for visualizing temporal changes in pulse morphology and the relationship between signals (see Fig. 3).

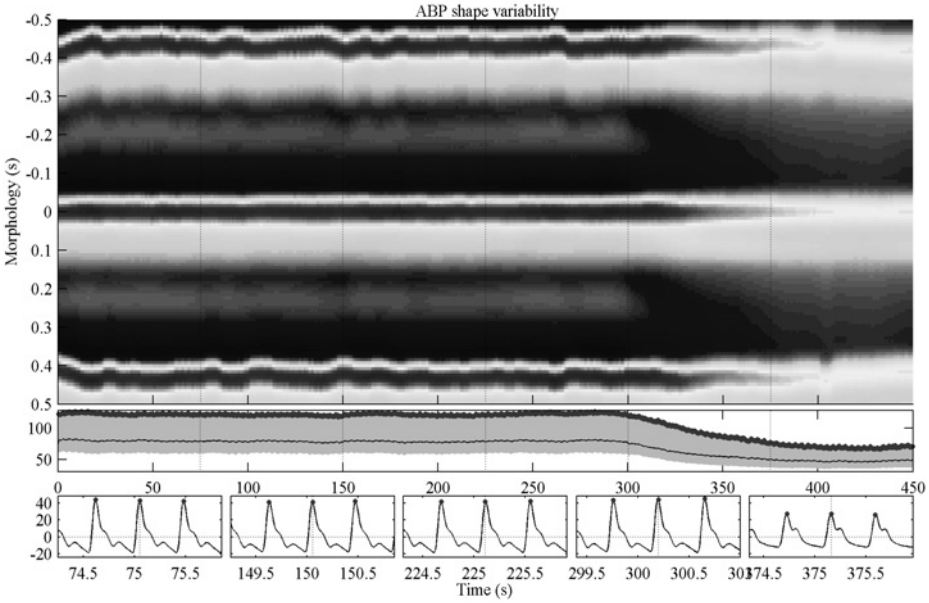

Fig 4. Example of the shape visualization function applied to an ABP signal to detect changes in the morphology of the ABP signal beats during an episode of acute hypotension in a pediatric patient with shock. The top plot shows the change in morphology versus time. The middle plot shows the ABP time series, the detected percussion peak in red, and the lowpass filtered signal. The bottom plot shows examples of time domain segments from which the beats were constructed

4 Discussion

The BSP toolbox is designed for rapid preliminary research on physiologic signals. In Figs. 3 and 4 we show examples of two of the visualization tools included in the toolbox. In the case of Fig. 4, the change in beat morphology is an example of a feature that is difficult to visualize by simple visual inspection of the time series (plot B). The shape visualization function uses the beat detection algorithm to identify the waveform components.

This figure was generated with the following MATLAB function call: Beatogram(ABP,125). This function only required a vector containing a segment of the signal (ABP) and the sampling rate (125 Hz).

5 Conclusions

The BSP toolbox described in this paper provides the means to perform rapid preliminary analysis of physiologic signals. The toolbox is user friendly and thoroughly documented. The toolbox will be publicly released at http://bsp.pdx.edu in June, 2002

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