Development of Heart Rate Variability Analysis Tool for the Assessment of Autonomic Function

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Abstract-**The Autonomic Nervous System (ANS) plays an important role in regulating body functions. Any abnormality or malfunction of the ANS will therefore affect multiple organs and systems. Heart Rate Variability (HRV) has been proposed as a non-invasive tool to assess this function. This paper presents the development of HRV analysis tool in order to reveal the ANS function by examining the interaction between the sympathetic and parasympathetic autonomic balance. This assessment tool consists of three stages. First, ECG acquisition, which involves the recording of Electrocardiograph (ECG) during Autonomic Function Tests (AFT) - Cold Pressor Test (CPT), and Active Postural Test (APT). Next, is pre-processing, followed by feature extraction. The feature extraction process uses Fast Fourier Transform (FFT) and Autoregressive (AR) spectral analysis to analyse the HRV. The extracted features are the normalized unit of High Frequency (HFnu), normalized unit of Low Frequency (LFnu), and LF/HF ratio. These features are able to distinguish between various frequency bands, responding to the different sympathetic and parasympathetic activities of the ANS. This tool was developed using MATLAB software. In conclusion, this tool is able to provide easy and simple, yet precise, analysis for the assessment of ANS - sympathetic and parasympathetic autonomic balance. This promising tool can then be used for further investigation, to assess the occurrence of ANS disorders.**

Keywords-**Autonomic Nervous System, Heart Rate Variability, Autonomic Function Test, Fast Fourier Transform, Autoregressive**

I. INTRODUCTION

The Autonomic Nervous System (ANS) is divided into two systems, namely the Sympathetic Nervous System (SNS) and the Parasympathetic Nervous System (PNS). The SNS functions to prepare the body for emergencies or stress, while the PNS is most active under ordinary and relaxed conditions. To assess the interaction between these functions, an invasive tool, called Heart Rate Variability (HRV), is used. HRV is defined as the variation over time of the period between consecutive heartbeats. HRV reflects the ability to reveal the functions of the ANS and understand its status.

Spectral analysis of HRV is able to distinguish between the various frequency bands that respond to the different sympathetic and parasympathetic activities of the ANS. In frequency modulations of heart rate, Low Frequency (LF) ranges (0.04–0.15 Hz) indicate predominance of sympathetic activity, whilst High Frequency (HF) ranges (0.15–0.4 Hz) are associated with a parasympathetic predominance [1]. This paper presents the development of an HRV assessment tool, in order to reveal the ANS's function, by examining the interaction between the sympathetic and parasympathetic autonomic balance. Fast Fourier Transform (FFT) and Autoregressive (AR) spectral analysis are used to analyse HRV.

II. MATERIALS AND METHODS

The HRV analysis tool was designed for offline use. Therefore, Electrocardiograph (ECG) acquisition needs to be performed before passing through the analysis tool.

A. ECG Acquisition

ECGs with a 600Hz sampling rate were recorded from healthy subjects, during sessions between 8.00am and 12.00pm. Two Autonomic Function Tests (AFT) were carried out, namely Cold Pressor Test (CPT) – which is hand immersion in cold water for three minutes together with a five minute baseline measurement, before and after hand immersion; and Active Postural Test (APT) – which is five minutes in the supine position, followed by five minutes in a standing position.

B. Development of the HRV Analysis Tool

The analysis tool was developed using MATLAB software consisted of two stages: First, the design of Graphical User Interface (GUI) and second, the design of analysis program; which consisted of pre-processing and spectral analysis. The flow diagram of the analysis tool is shown in Fig. 1.

Pre-processing: The recorded ECG signals are pre-processed to quantify HRV. QRS waves are then detected, using Pan and Tompkin's algorithm, and resampled to 4Hz. The algorithm begins by passing the signal through a digital band-pass filter, in order to attenuate noise. The process continues with differentiation, followed by squaring, and moving window integration. Next, the locations of R points are classified by adaptive thresholds. The R-R intervals are then computed and passed through several more processes, which include the removal of outliers, signal resampling to 4Hz, and de-trending.

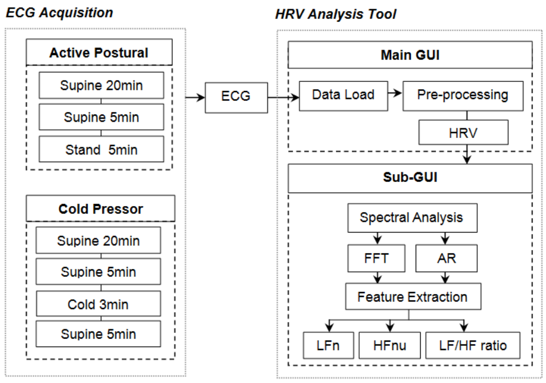


Fig. 1: Flow Diagram of the Analysis Tool

Feature Extraction: FFT is a classical analysis method used to transform signals into the frequency domain. The general discrete Fourier transform equation, employed for FFT is:

$$X(k) = \sum_{n=0}^{N-1} x(n)e^{-jw_k n} \qquad (1)$$

Where, *x(n)* is the sampled HRV signal, and N is the number of data points in frames [2]. Besides FFT, Auto Regressive (AR) analysis was also applied in several study's analyses. The AR model is defined as:

$$x[n] = \sum_{i=1}^{M} a_i x[n-1] + \varepsilon[n] \qquad (2)$$

Where, $x[n]$ is the current value of the HRV time series, $a1, \ldots, aM$ are predictor coefficients, M is the model order, which indicates the number of past values used to predict the current value, and $\varepsilon[n]$ represents a one-step prediction error i.e., the difference between the predicted value and the current value at this point [3].

For AFT studies, the features that are commonly extracted from the frequency spectrum, are the powers of Low Frequency component (LF), High Frequency component (HF), LF/HF ratio, and the normalized unit (n.u) of LF and HF (called LFnu and HFnu). The LFnu and HFnu are described below:

$$LFnu = \frac{LF}{TP-VLF}\, x\ 100 \qquad (3)$$

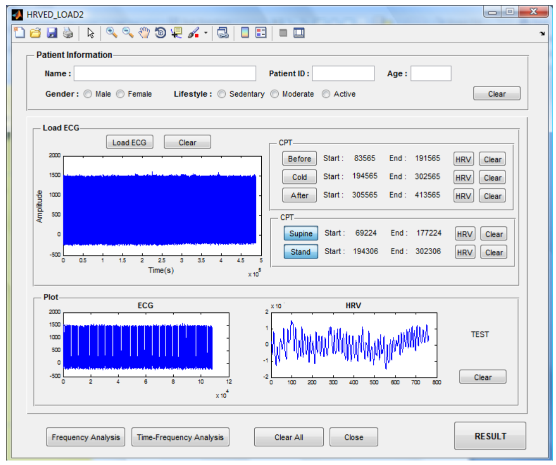
$$HFnu = \frac{HF}{TP-VLF}\, x\ 100 \qquad (4)$$

Where, *VLF* is the power of the Very Low Frequency component and *TP* is the total power of the spectral analysis [1].

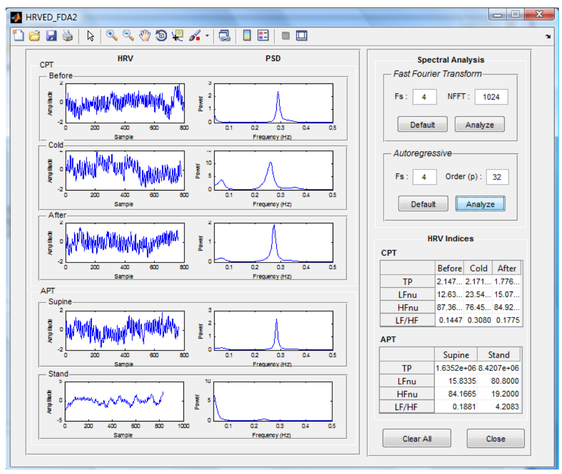
III. Results and Discussions

The GUI was divided into two linked interfaces. The main GUI functioned to load the recorded ECG; segmented into the required length (Fig. 2(a)). The signal then passed through pre-processing to produce HRV as the input for the sub-GUI. The HRV feature extraction was executed in the sub-GUI (Fig. 2(b)). The analysis offered the following two options of extraction; either FFT or AR spectral analysis.

Analysis of HRV during AFT was made to obtain partial results, in order to see the significant response of each test. From the analysis, we found that during the supine position, the High Frequency (HF) component was increased and the Low Frequency (LF) component was decreased. This result indicates a parasympathetic predominance; where the body was in a relaxed condition. However, when the subject changed to a standing position, the high frequency component was almost diminished and the low frequency component was increased. This change indicated a sympathetic predominance; where the body was in an active condition, working to maintain the standing position, by supplying blood to the legs.



(a)



(b)

Fig. 2: Graphical User Interface (GUI) of HRV analysis tool

When the body was stimulated by the cold pressor, the LFnu (which indicates sympathetic predominance) was increased, and therefore reduced the HFnu (i.e., parasympathetic activity) [4]. This is because, during the cold pressor test, the sympathetic system withstands the pressor on the hand [5]. After the subject extricated their hand, the autonomic response returned to normal (i.e., before hand immersion) with a higher HFnu and a Lower LFnu. The details of this preliminary result can be found in [6].

In conclusion, this tool is able to provide easy, simple, yet precise analysis, for the assessment of ANS - sympathetic and parasympathetic autonomic balance. This promising tool can then be used for further investigations, to assess the occurrence of ANS disorders.

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