Heart Rate Variability (HRV) Based Feature Extraction for Congestive Heart Failure

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Abstract: Heart Rate Variability (HRV) signal which is providing information about variation between consecutive heartbeats has been employed for extracting the parameter related to Congestive Heart Failure (CHF) from Electrocardiography (ECG). There are several studies on HRV analysis and CHF however most of the studies were performed by text-based methods. The main objective of this work is not only search to extract parameters but also to accomplish the difficulties in the text based program. This study presents graphical programming language to investigate features of HRV. Graphical User Interface (GUI) has been developed in LabVIEW to create some method for extraction features related to CHF. HRV are analyzed in the time and frequency domains. Parameters related to the time and frequency domains are derived for healthy ECG and ECG signals having Congestive Heart Failure. Several parameters which are necessary for classification algorithms are obtained.

Key words: Congestive Heart Failure (CHF), Electrocardiography (ECG), Heart Rate Variability (HRV), LabVIEW.

1. Introduction

Cardiovascular disease (CVD) is caused by disorders of the heart and blood vessels [1]. It includes diseases that affect the circulatory system such as; coronary heart disease (heart attacks), cerebrovascular disease (stroke), raised blood pressure (hypertension), congestive heart failure, congenital heart disease, and heart failure. According to the World Health Organization, estimated 17.3 million people died from CVDs in 2008. Over 80% of CVD deaths occur in low- and middle-income countries. According to information contained on the site of this organization, by 2030 more than 23 million people will die annually from CVDs. Heart failure, one of the CVD type, is very common and has become a major and growing health problem. It affects millions of people worldwide. Congestive Heart Failure (CHF) takes place when bottlenecks occur in the lungs or body tissues due to inadequate heart pumping [2], [3]. The symptoms of congestive heart failure vary such as; fatigue, diminished exercise capacity, shortness of breath. Early diagnosis and treatment of the disease are important. The diagnosis of heart related disease often made through an Electrocardiogram (ECG) method. ECG method is significant for diagnosis of heart failures [4]. It is non-invasive method. Recently, researchers have discovered that HRV can be used for investigation CHF.

An electrical signal received from body play an important role to analyze disturbance may occur in body. ECG is an electrical recording of the heart from certain places of skin with electrodes. ECG consists of P, T, U waves, and QRS complex [5]. Parameters derived from ECG are used to investigate diseases related to heart since the parameters have vital information about the heart operation. Usually, ECG signal is used to determine QRS complex, calculate number of beats per minute, find width of P and U waves, and analyze HRV

[6], [7].

The time between successive R-waves in the QRS complex of ECG or the fluctuation of time between consecutive heartbeats is called Heart Rate Variability (HRV) [8], [9]. A healthy heart does not have a fixed rhythm of heartbeat. Time variation occurs between heartbeats rhythmically, for instance, in general case, this time change between 2 seconds and 0.5 seconds. These changes are performed by the nervous system. Autonomic Nervous System (ANS) that regulates some function of body that cannot be carried out by brain with controlled manner such as digestion, excitement, breathing [10]. ANS tries to find the most effective way of body operating. ANS consists of two parts, called the sympathetic and parasympathetic. Parasympathetic has a decelerating effect on the body event while sympathetic has an accelerating affect. HRV gives significant information about ANS [11]. Hereby, HRV is considered as an important indicator of ANS. Mental stress, respiratory, metabolic, exercise, age, gender, etc. can be effective in changing the heart rate variability and changes of HRV related to specific pathologies such as; diabetes, arrhythmia. A normal heartbeat rate can range from 40 to 100 beats per minute but unfortunately there is no limitation for some parameter of HVR.

There are several studies on HRV analysis and CHF. Most of the studies were performed by text-based methods. In this study, it is focused on the development of GUI with LabVIEW to indicate tools of the LabVIEW provide convenient HRV analysis to extract classification parameter related to CHF. Noise from the raw signal was removed. Then time and frequency domain based analysis were made to extract features for both healthy ECG and ECG signals having CHF. Besides the developed interface, signals were examined using Biomedical Workbench applications.

2. Material and Methods

In this study, graphical interface was developed with LabVIEW 15.0 version. Static, histogram, FFT spectrum tools of Biomedical Toolkit were employed to analyze ECG signal and HRV. To analyze developed system, the ECG signals which found in LabVIEW software and BIDMC Congestive Heart Failure Database (chfdb) ECG signal received from MIT-BIH PhysioBank online database were used.

HRV analysis method can be divided in two sections which are time domain, frequency domain. In the following, these analysis methods are presented.

2.1. Database

Signals required for study are taken from the MIT-BIH PhysioBank database. Signals of four databases that are BIDMC Congestive Heart Failure Database (chfdb), Congestive Heart Failure RR Interval Database (chf2db), Normal Sinus Rhythm RR Interval Database (nsr2db) and MIT-BIH Normal Sinus Rhythm Database (nsrdb) were used to examine. PhysioBank database contains multiple signals in different formats. It provides a right to use data in free of charge.

2.2. The Graphical Programing Language Used

LabVIEW which is graphics-based software platform has been developed by the American National Instruments Company. It provides a visual platform for development of algorithms. Compared with the text-based language, usage of it is so simple that the number of users of it has been increased gradually [12] [13]. Due to its graphical represent and Biomedical Toolkits, it is preferred especially in biomedical fields.

There are a lot of different data file types in the biomedical signal processing field. LabVIEW has its own File Format Converter (FFC) application. It has ability to convert the PhysioBank data files in TDMS file type which is compatible with LabVIEW.

Graphical User Interface has created in LabVIEW 15.0 version. FFT, Wavelet Transform, Biomedical Toolkit and Advanced Signal Processing Toolkit of LabVIEW platform have employed to analyze HRV signal.

Fig. 1 shows the block diagram of developed GUI.

LabVIEW consists of two parts, front panel and block diagram. Block diagram corresponds to code writing part of text-based programming languages. Front panel is part of a program was taken out. The developed program was created with linking of graphical tools instead of writing code.

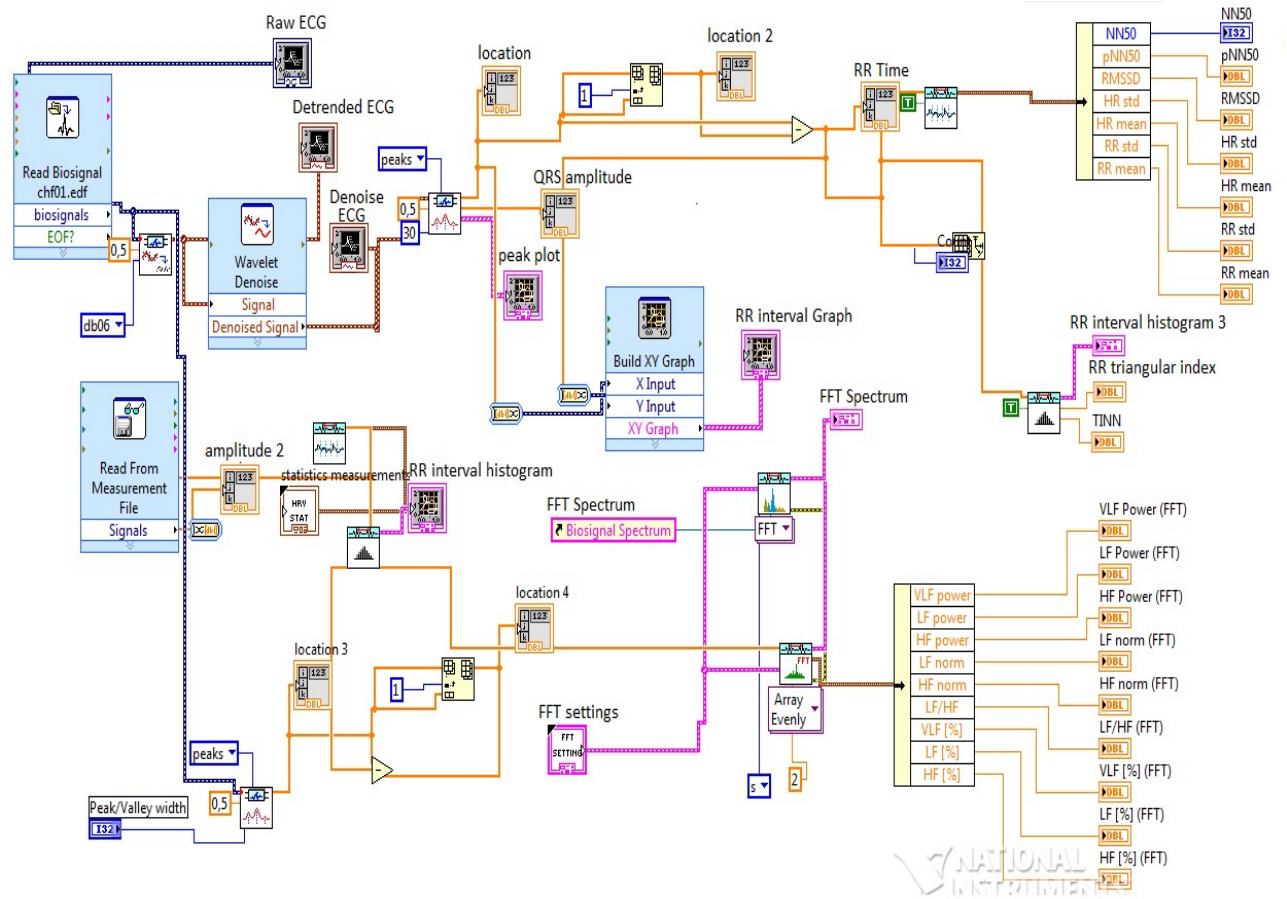

Fig. 1. Block diagram of designed system.

2.3. Preprocessing

ECG signals are recorded with many noise such as muscle noise, grid noise, noise caused by the circulatory system. These noises must be suppressed in order to get correct required information from the signal [14]. Therefore, in this section, the high and low frequency components are removed from the signal as shown in Fig. 2.

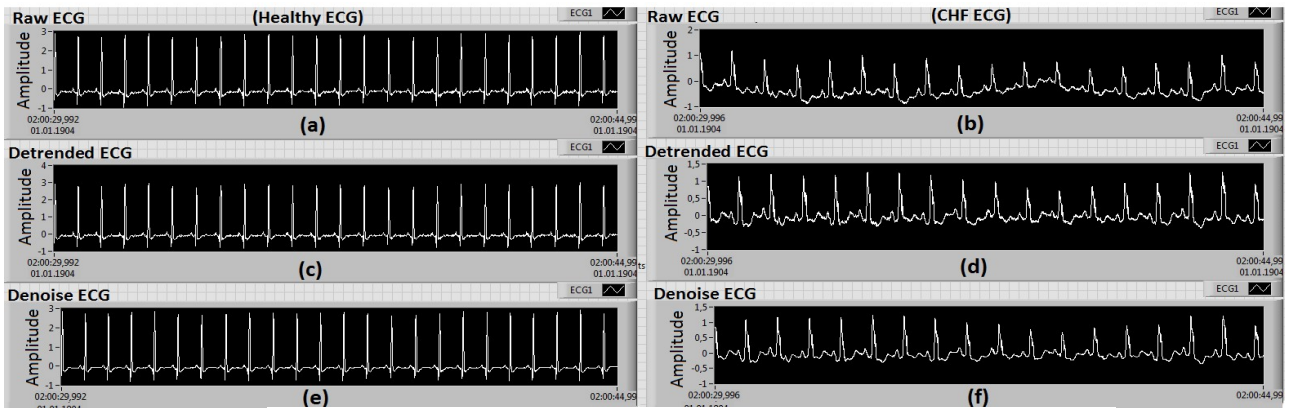

Fig. 2. Remove the low frequency trend and wideband noises of both signals.

Raw healthy ECG and CHF ECG are indicated in Fig. 2a and 2b, respectively. Low frequency components are removed from both signal as shown in Fig. 2c, and 2d. High frequency components are removed from both signal as indicated in Fig. 2e, and 2f. Wavelet transform tool were used to remove high and low frequency signal components. WA Detrend VI tool was used to remove the low frequency trend of a signal. Other types of noise or wideband noises were removed via the Wavelet Denoise Express VI. For the purpose of diagnosis, it is often need to extract various features from the preprocessed ECG data, including QRS intervals, QRS amplitudes, etc. HRV analysis is based on the detection of the RR point in QRS complex [15]. So, detection of the RR point is necessary. In study, Wavelet-based peak detection tool was used for the determination of RR peak. R peaks in the overall signal was detected successfully. Then, time difference between the RR points was calculated. Fig. 3 shows a different time of QRS complex. Fig. 4 shows R point for both signals by a red X mark.

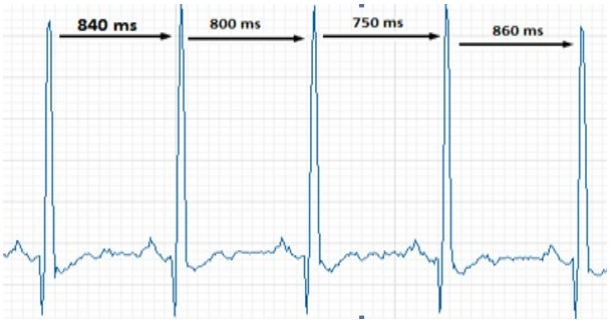

Fig. 3. Time between RR intervals of ECG signal.

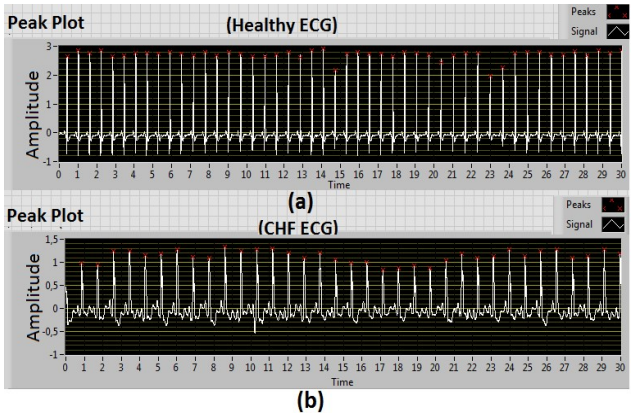

Fig. 4. R peaks detection in healthy ECG (a) and CHF ECG. (b).

2.4. Time Domain Features

Time domain analysis provides extracting many measurements from raw RR interval signals. The simplest variables derived directly from RR interval signals are the time domain parameters. RR signals are obtained by detected QRS complex in ECG [16]. Some variable related to RR interval such as; RR Mean & Std, HR Mean & Std, RMSSD, NN50 Count, pNN50 were calculated. Table 1 shows the description of these variables.

Table 1. Time-Domain Measurements of Heart Rate Variability

Variable	Unit	Description
NN	ms	Time between two consecutive beats.
RR std	s	Standard deviation of all RR interval
RR mean	s	Mean of all RR interval
HR mean	1/min	Mean of all heartbeat
HR std	1/min	Standard deviation of all heartbeat
RMSSD	ms	The square root of the mean squared differences of successive NN intervals
NN50 Count	N/A	Number of pairs of adjacent RR intervals differing by more than 50 ms in all the measurements.
pNN50	%	NN50 count divided by the total number of all RR intervals.

The values of the above variables for both normal ECG and CHF ECG are shown in Fig. 5a, Fig. 5b, respectively. Furthermore, histogram of RR interval derived for both signal are shown in Fig. 5. Research on

HRV time domain studies generally examine some of the above variables. However, the developed graphical-based algorithm enables to calculate all of them.

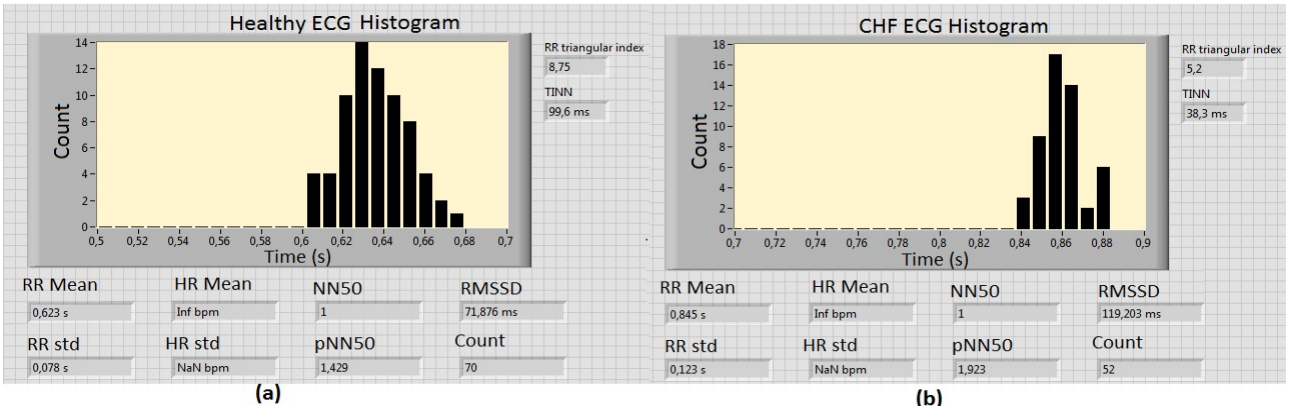

Fig. 5. The time-domain measurements of normal (a) and failure ECG (b).

2.5. Frequency Domain Features

Sympathetic and parasympathetic content of ANS cannot be evaluated from time domain based method. However, frequency domain method of HRV analysis shows the some parameters which demonstrate the state of the ANS [17]-[19]. Frequency domain technique uses Power Spectral Density (PSD). PSD allows the calculation of different spectral components [20], [21]. There are two methods to calculate PSD of the HRV. They are nonparametric and parametric method. Nonparametric method employs FFT and parametric employ Autoregressive (AR) method. Both have some advantage and disadvantage to each other. There are many studies about it. In most cases employed FFT which is a simple method and the high processing speed are the advantages of the nonparametric method while smoother spectral representation and accurate estimation of PSD even on a small number of samples on that the signal are the advantage of the parametric method.

Short-term recording of HRV commonly describes in three different spectral components which are Very Low frequency (VLF between 0-0.033Hz), Low frequency (LF between 0.033-0.15), and High frequency (HF between 0.15-0.4). Long-term recording of HRV can be used for investigate another spectral components. Low frequency components are about the sympathetic nervous system, high frequency components show varies of the parasympathetic nervous system of ANS. Imbalance of LF/HF proportion can cause deterioration of cardiac function in future. Fig. 6 shows the FFT based features of both signals. PSD belong to healthy ECG have more LF/HF balance than failure ECG as shown in Fig. 6.

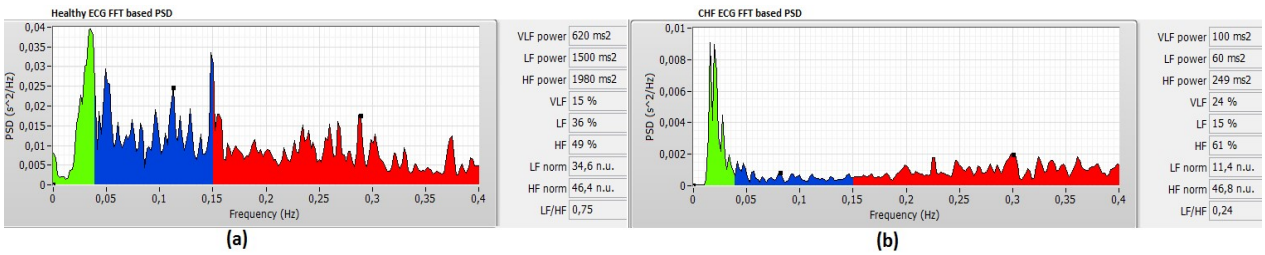

Fig. 6. FFT based PSD of normal ECG (a) and failure ECG (b).

Fig. 7 shows the AR based features of both signals. PSD obtained by FFT is rougher than AR method. As similar to FFT based PSD, PSD belong to healthy ECG have more LF/HF balance than failure ECG as shown in Fig. 7.

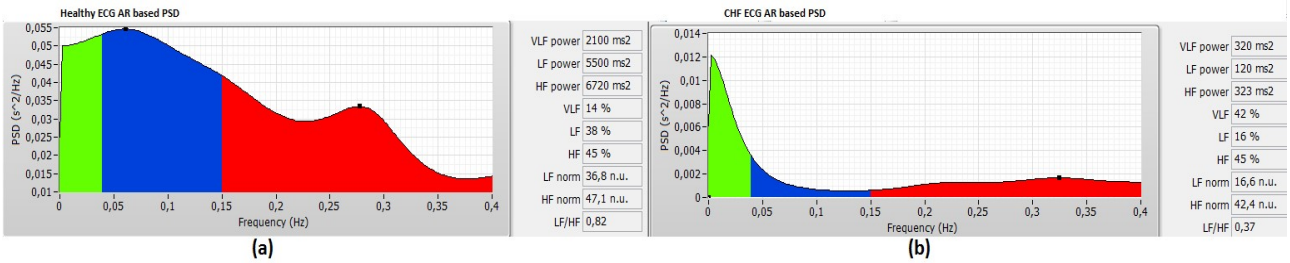

Fig. 7. AR based PSD of normal ECG (a) and failure ECG (b).

The spectral component of short-term HRV calculated by using FFT and AR methods of both signals. Peak frequency and power of these different frequency bands were calculated to extract PSD. The resampling RR interval is needed to use RR interval for PSD calculation [22]. Since RR interval, along the time axis, are irregularly distributed. 2 Hz interpolate rate was enough to obtain best result.

3. Discussion and Conclusion

Heart failure is very common and has become a major and growing health problem. It affects millions of people worldwide. Early diagnosis and treatment of the disease is important. Medical diagnostic systems usually consist of three stages that are preprocessing, characteristic extraction and classification. For a successful classification, characteristic features to define the signal are necessary. This study investigates HRV-based methods for extract features to recognize CHF. Two signals were studies. There were normal sinus rhythm ECG signals and Congestive Heart Failure ECG. We observed that developed structure able to extract parameters from HRV signals and showed differences between the two signals successfully. HRV may be evaluated by a number of methods. However, most of the works studied it partially or has been made by conventional method. LabVIEW is relatively new graphical software. It is an important tool especially for studying biomedical signal [23]-[25]. In this study, a lot of parameters were investigated together with the developed LabVIEW algorithm because of its most effective signal processing capability. Designed structure can be employed by doctors or patients to observe their HVR thanks to simple usage of graphical structure.

The future works will include classification methods for further analysis to make specific link between parameters for CVH and healthy ECG signals. Parameters of HRV under different conditions will be extensively investigated through different methods. Also different signals related to the heart will be investigated.

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References

[1] Sumathi, S., Lilly Beaulah, H., & Vanithamani, R. (2014). A wavelet transform based feature extraction and classification of cardiac disorder. *Journal of medical systems, 38(9),* 1-11.

[2] Liao, K. Y. K., Chiu, C. C., & Yeh, S. J. (2015). A novel approach for classification of congestive heart failure using relatively short-term ECG waveforms and SVM classifier. *Proceedings of the International Multi Conference of Engineers and Computer Scientists, vol. 1.*

[3] Liu, C., Zheng, D., Zhao, L., Li, P., Liu, C., & Murray, A. (2014). Analysis of cardiovascular time series using multivariate sample entropy: A comparison between normal and congestive heart failure subjects. *Proceedings of Computing in Cardiology Conference (CinC),* (pp. 237-240). IEEE.

[4] Martis, R. J., Acharya, U. R., & Min, L. C. (2013). ECG beat classification using PCA, LDA, ICA and Discrete Wavelet Transform. *Biomedical Signal Processing and Control, 8(5),* 437-448.

[5] Guzel, S., Kaya, T., Guler, H., & Akbal, A., (2014). LabVIEW-Based Analysis and Interpretation of ECG Signals. VII. URSI. Scientific Congress, 28-30 August 2014, Elazig, Turkey.

[6] Zhang, C. F., & Bae, T. W. (2012). VLSI friendly ECG QRS complex detector for body sensor networks. *IEEE Journal on Emerging and Selected Topics in Circuits and Systems, 2(1),* 52-59.

[7] Martis, R. J., Acharya, U. R., Lim, C. M., & Suri, J. S. (2013). Characterization of ECG beats from cardiac arrhythmia using discrete cosine transform in PCA framework. *Knowledge-Based Systems,* 45, 76-82.

[8] Sharma, M. L., Verma, R. K., Rizvi, N. F., Malhotra, A., Sharma, S., & Sharma, N., (2011). Heart rate variability (HRV) measurement-A methodological-application of low frequency measurement in LabVIEW. *International Journal of Computer Science and Network Security*, *11(2),* 105-108.

[9] Bansal, D., Khan, M., & Salhan, A. K. (2009). A review of measurement and analysis of heart rate variability. *International Conference on Computer and Automation Engineering,* (pp. 243-246). IEEE.

[10] Yu, S. N., & Lee, M. Y. (2015). Wavelet-based multi scale sample entropy and chaotic features for congestive heart failure recognition using heart rate variability. *Journal of Medical and Biological Engineering, 35(3),* 338-347.

[11] Niskanen, J. P., Tarvainen, M. P., Ranta-Aho, P. O., & Karjalainen, P. A. (2004). Software for advanced HRV analysis. *Computer methods and programs in biomedicine*, *76(1),* 73-81.

[12] Guler, H., & Ata, F. (2014). The comparison of manual and LabVIEW-based fuzzy control on mechanical ventilation*. Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*.

[13] Adochiei, N. I., Dorffner, G., & David, V. (2012). Heart rate variability monitoring due to 50 Hz electromagnetic field exposure and statistical processing. *Proceedings of International Conference and Exposition on Electrical and Power Engineering (EPE),* (pp. 610-613). IEEE.

[14] Kaya, T., & Ince, M. C. (2012). Design of FIR filter using modeled window function with helping of artificial neural networks. *Journal of the Faculty of Engineering & Architecture of Gazi University, 27(3).*

[15] Isler Y., (2009). *A detailed analysis of the effects of various combinations of heart rate variability indices in congestive heart failure.* Ph.D. Thesis, Dokuz Eylul University, İzmir, Turkey.

[16] Using LabVIEW for Heart Rate Variability Analysis- http://www.ni.com/example/30832/en/

[17] Desai, K. D., Jadhav, S. D., & Sankhe, M. S. (2013). A comparison and quantification of fetal heart rate variability using Doppler ultrasound and direct electrocardiography acquisition techniques. *2013 International Conference on Advances in Technology and Engineering (ICATE),* (pp. 1-8). IEEE.

[18] Yildiz, M., & Turkoglu, Z., (2014). Feasibility of heart rate variability analysis with heart sounds. *22nd Signal Processing and Communications Applications Conference (SIU).* IEEE.

[19] Yazgı, S., & Yıldız, M., (2009). The effect of swallowing on the heart rate variability. *TURKMIA'09 Proceedings 276 VI. National Congress of Medical Informatics* ENMI, No 1.

[20] Allen, B., Jennings, J. R., Gıanaros, P. J., Thayer, J. F., & Manuck, S. B,. (2014). Resting high-frequency heart rate variability is related to resting brain perfusion. *Psychophysiology, Wiley Periodicals, Inc. Printed in the USA. Society for Psychophysiological Research*.

[21] Narin, A., Ozer, M., & Isler, Y. (2013). Comparisons of classifier performances in diagnosing congestive heart failure using heart rate variability. *2013 21st Signal Processing and Communications Applications Conference (SIU),* (pp. 1-4). IEEE.

[22] Koenig, J., Jarczok, M. N., Kuhn, W., Morsch, K., Schäfer, A., Hillecke, T. K., & Thayer, J. F. (2013). Impact of caffeine on heart rate variability: a systematic review. *Journal of Caffeine Research*, *3(1),* 22-37.

[23] Guzel, S., Kaya, T., & Guler, H. (2015). LabVIEW-based analysis of EEG signals in determination of sleep stages. *2015 23th Signal Processing and Communications Applications Conference (SIU),* (pp. 799-802). IEEE.

[24] Guler, H., Turkoglu, I., & Ata, F. (2014). Designing intelligent mechanical ventilator and user interface using LabVIEW®. *Arabian Journal for Science and Engineering, 39(6),* 4805-4813.

[25] Guler, H., & Ata, F., (2014). Development of a Fuzzy-Based Tidal Volume Algorithm for Patients With Respiratory Distress. *Journal of the Faculty of Engineering and Architecture of Gazi University*, *29(4),* 699-706.

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