International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 1s,2025
https://theaspd.com/index.php

Biomedical Signal Processing For Heart Rate Variability

Deepak Kumar Sahu[1],Priyanka Gupta[2],Parveen Kaur[3]
[1]Assistant Professor, Department of Pharmacy, Kalinga University, Raipur, India. ku.deepakkumarsahu@kalingauniversity.ac.in,0009-0007-2995-1175
[2]Assistant Professor, Department of Chemistry, Kalinga University, Raipur, India.
[3]Assistant Professor, New Delhi Institute of Management, New Delhi, India., parveen.kaur@ndimdelhi.org, https://orcid.org/0000-0002-5750-7115

Abstract
The significance of HRV in science and heart health is becoming increasingly evident as study on it expands. Artificial intelligence, machine learning techniques, and frequency domain analysis of HRV have the ability to significantly impact people's life quickly if they are accurate. That's why researchers are constantly refining these methods to enhance patient health, reduce the risk of road accidents, and improve overall quality of life. Many researchers are actively focusing on ambulatory detection of HRV in order to dramatically and favorably impact the health and well-being of individuals dealing with chronic stress, diabetes, hypertension, cardiovascular disease (CVD), and myocardial infarction. To prevent major health emergencies, it is imperative that these patients be watched all day. For elderly or chronically ill patients with cardiovascular problems who find it difficult to visit hospitals on a regular basis because of physical limitations and distance, remote HRV monitoring could be a game-changer.
Keywords: *heart rate variability, wireless sensors, drowsiness, stress, morbidity, exercise*

INTRODUCTION

Changes in the ECG signal time period are the cause of heart rate variability. The autonomic nerve system, which the body has built, regulates this variation in heart rate throughout time. The HRV power spectrum allows for the monitoring of slow-developing diseases that impact the heart and respiratory systems. To determine the state of the health system, this power spectrum can be utilized as a health signature [1]. The sympathetic and parasympathetic nerve systems are balanced by the changing signal that is heart rate. Indicators of current illness or cautions about upcoming or prospective cardiovascular disorders may be found in the heart rate fluctuation. These signs could exist continuously or happen at random at specific points in time. Finding these anomalies in massive cardiac data is challenging and time-consuming. In order to investigate the autonomic nervous system (ANS) during fetal gestational development, we have developed a computer-based analytical system in this work that measures heart rate and analyzes it to produce HRV Power-spectrum [9]. The HRV power-spectra power values (= areas beneath the power-spectrum plot between spectral peaks) and the frequency shift of the peaks from their normal frequency values are the basis for the indices we have assigned[2]. We have demonstrated the sensitivity and effectiveness of these indices in distinguishing between fetal growth that is normal and that which is aberrant[3]. As a result, we have shown how well these HRV power-spectral indices can facilitate early fetal autonomic nervous system identification [15]. We have shown how well the quantitative amplitude and estimate of the cardiac ANS activity can be obtained from spectral analysis of the HR variations. In order to make it easier to differentiate and diagnose prenatal autonomic neuropathy using a single index or number, we have finally created an integrated index composed of various power-spectral indices. [10].

REVIEW OF LITERATURE

The literature review was conducted using the online resources of the Ryerson University Library and Archives (RULA). To access the databases PubMed, IEEE Xplore, Web of Science (WoS), and Scopus, we mostly used RULA. Using PPG, RESP, EDA, and ECG signal analysis, we focused on HRV investigations. While several studies made reference to EEG or EOG analysis, they were disregarded since they did not primarily focus on ECG, EDA, RESP, and PPG[4]. We were careful to analyze articles released after 2010 to ensure the data was current, with the exception of one publication that illustrated the application of time and frequency domain analysis. The relevant studies we examined provided a thorough exploration of the health conditions linked to HRV, and we excluded any papers that only

skimmed the surface. We also disregarded those that concentrated on factors unrelated to HRV. In total, we reviewed over 70 papers, but many were not suitable for meta-analysis as they lacked a detailed examination of HRV in relation to cardiac issues, exercise, or drowsiness. After filtering out repetitive topics, we delved into 18 key concepts derived from 25 articles [5].
A review paper by Kim and colleagues explores the connection between stress and heart rate variability (HRV). They investigated the effects of stress on human bodies, paying special attention to the structure of the heart and brain that contribute to these alterations. The most recent advancements in wearable technology for data collection, the various signal processing algorithms used to extract and analyse HRV features, and the machine learning techniques used to classify different medical conditions were all left out of the paper, despite the fact that it provided insightful information about the physiological effects of stress. Additionally, it overlooked the potential of wireless HRV monitoring to enhance healthcare systems and improve patient outcomes, along with the wide range of applications tied to HRV research [11].

MATERIALS AND METHODS

HRV has a lot of different applications, and we've touched on some of them. In the sections that follow, we'll take a closer look at several studies that have looked at HRV, analysing the ways in which specific activities and medical conditions impact a patient's or subject's HRV. We will also highlight the flaws and inconsistencies in each study and provide suggestions for future research methodologies in order to increase HRV's effectiveness and positively influence people's lives while preventing unfavourable outcomes. The patterns and development of HRV, from the first investigations to the most recent, will be discussed in this part. The particular heart rate oscillations under steady state settings are a reflection of the autonomic regulation of SA node activity from beat to beat [6]. Both sympathetic and parasympathetic neurons enervate the SA node, the heart's primary pacemaker. The heart rate is slowed by parasympathetic nerve activity and raised by sympathetic nerve activity. Modulations at low, medium, and high frequencies have been observed in clinically determined heart rate fluctuations. These oscillations are pseudo-periodic and have a cardiovascular origin. Even in the absence of rhythmic disruptions, they repeat themselves in time, with a period that oscillates around a particular mean value [7]. These oscillations are now understood to be physiological rhythms, signifying the neurocardiac control of heart rate and blood pressure.

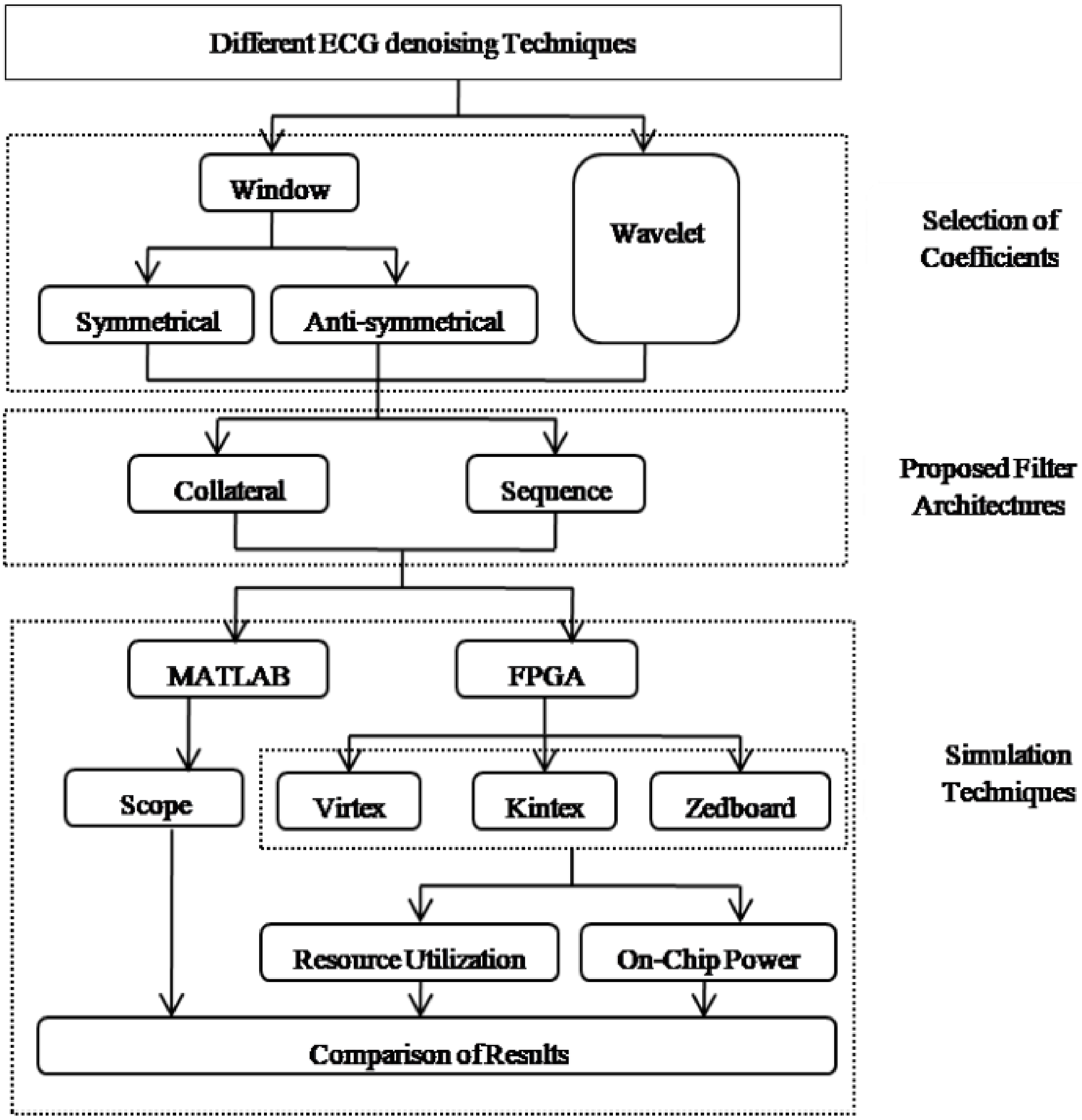

Figure 1: Design flow

They just aren't up to the standard needed to effectively help those dealing with stress or poor heart rate variability (HRV). Unlike wearable ECG sensors, smartphones aren't built to encourage a healthy lifestyle [8]. If we wanted to use them to diagnose work-related stress, we'd need to tweak their design to make them more suitable for healthcare applications.

RESULT AND DISCUSSION

Smartphones and wireless devices for ECG, EEG, and EDA are paving the way for early detection of cardiovascular diseases linked to HRV impairment, before they escalate into serious and life-threatening conditions. These technologies empower healthcare professionals and individuals dealing with various cardiovascular issues, like diabetes and hypertension, to take proactive steps and reduce the risk of severe complications by keeping an eye on their physiological activity throughout the day, even while they sleep. With the help of machine learning, they can also anticipate stress and negative emotions tied to their daily routines, allowing them to adjust certain activities for improved productivity and a greater sense of well-being [12].

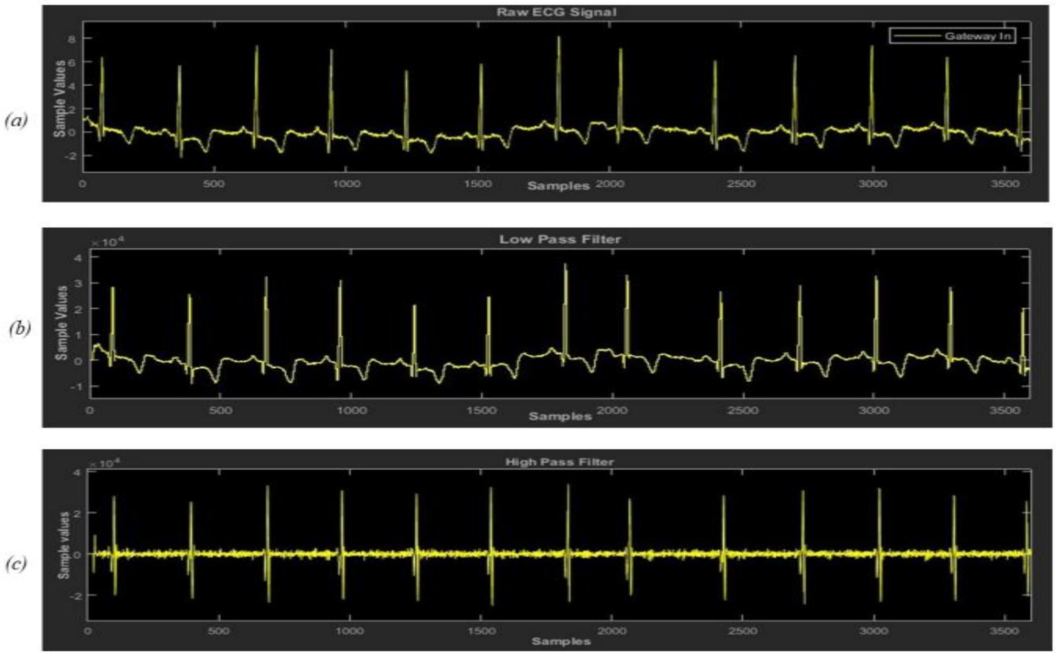

Figure 2: Scope results

The information acquired was crucial in the development of WESAD, a public database intended to facilitate efficient emotional state and stress level analysis [13]. Cho et al. used information from a PPG, EDA, and SKT to investigate skin temperature (SKT), skin conductance (SC)/sweat, and heart rate variability (HRV).

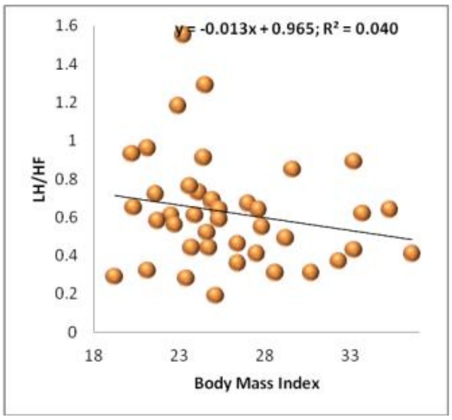

Figure 3: Correlation between the low frequency/high frequency (LH/HF) ratio

They were able to classify stress with amazing accuracy by combining integrated information with a state-of-the-art feedforward neural network approach.

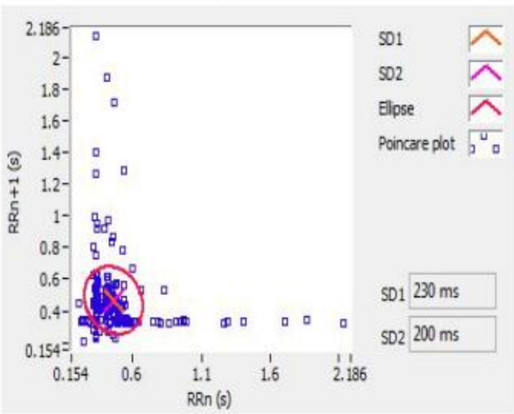

Figure 4: Point care chart

Wearable technology can assess HRV accurately at rest with 85% accuracy with a PPG and an impressive 99% accuracy with an ECG, but this accuracy drops to 85% during exercise, according to their research [14].

CONCLUSION

This article dives into various summaries and reviews related to HRV research applications, highlighting that lower HRV is linked to higher morbidity and stress levels. When HRV drops, it often signals increased sympathetic nervous system (SNS) activity, which can raise heart rate and blood pressure. This reaction is the body's way of responding to perceived threats, working to keep everything in balance and maintain homeostasis. However, HRV in motion tends to be less effective compared to findings from other studies, particularly those focusing on stress and heart attacks. Many studies have pointed out the inaccuracies in detecting exercise and drowsiness, an area of HRV research that definitely needs more focus. Enhancing this could help avoid accidents brought on by sleepy driving or injuries from performance tiredness before to sporting activities.

REFERENCES

1. Rangayyan, Rangaraj M., and Sridhar Krishnan. *Biomedical signal analysis*. John Wiley & Sons, 2024.
2. Abishek, U., Abishek, R. S., Sanjay, J., & Mounika, S. (2023). IOT-Based Soil Moisture Detection Using Arduino with A Farmer's Guidance App. International Journal of Advances in Engineering and Emerging Technology, 14(1), 164–167.
3. Gokhale, A., & Kaur, A. (2024). Language Loss and Cultural Identity in Minority Ethnic Groups. Progression Journal of Human Demography and Anthropology, 2(2), 13-16.
4. Rao, I., & Saxena, M. (2025). Exploring the Connections of the Mental Health and Sustainability. International Journal of SDG's Prospects and Breakthroughs, 3(1), 8-14.
5. Mateo, Javier, and Pablo Laguna. "Improved heart rate variability signal analysis from the beat occurrence times according to the IPFM model." IEEE Transactions on Biomedical Engineering 47, no. 8 (2002): 985-996.
6. Chopra, N., & Patil, V. (2025). Design of Advancements in AI for Cyber Threat Detection. In Essentials in Cyber Defence (pp. 16-34). Periodic Series in Multidisciplinary Studies.
7. Cerutti, Sergio, Maria Gabriella Baselli, Anna Maria Bianchi, Enrico Caiani, Davide Contini, Rinaldo Cubeddu, Fabio Dercole et al. "Biomedical signal and image processing." IEEE pulse 2, no. 3 (2011): 41-54.
8. Trisiana, A. (2024). A Sustainability-Driven Innovation and Management Policies through Technological Disruptions: Navigating Uncertainty in the Digital Era. Global Perspectives in Management, 2(1), 22-32.
9. Mateo, Javier, and Pablo Laguna. "Analysis of heart rate variability in the presence of ectopic beats using the heart timing signal." IEEE Transactions on biomedical engineering 50, no. 3 (2003): 334-343.
10. Ishaque, Syem, Naimul Khan, and Sri Krishnan. "Trends in heart-rate variability signal analysis." Frontiers in Digital Health 3 (2021): 639444.
11. Cerutti, Sergio, Ary L. Goldberger, and Yoshiharu Yamamoto. "Recent advances in heart rate variability signal processing and interpretation." IEEE Transactions on Biomedical Engineering 53, no. 1 (2005): 1-3.
12. Clifford, G. "Signal processing methods for heart rate variability." PhD diss., Oxford University, UK, 2002.
13. Carter, E., & Heinriksen, L. (2023). Performance Analysis of Ceramic Membranes in Treating Textile Wastewaters. Engineering Perspectives in Filtration and Separation, 1(1), 13-15.
14. Wei, L., & Johnson, S. (2024). Standardized Terminology for Symptom Reporting in Telemedicine Consultations. Global Journal of Medical Terminology Research and Informatics, 2(2), 14-17.
15. Baselli, Giuiseppe, Enrico Caiani, Alberto Porta, Nicola Montana, Maria Gabriella Signorini, and Sergio Cerutti. "Biomedical signal processing and modeling in cardiovascular systems." Critical Reviews™ in Biomedical Engineering 30, no. 1-3 (2002).