

# Biomedical Signal Processing: Advancements for Healthcare

Marcus E. Chen\*

*Department of Smart Healthcare Systems, University of Sydney, Sydney, Australia*

## Introduction

The field of biomedical signal acquisition is undergoing a rapid transformation, driven by advancements in wearable sensor technology and miniaturized devices. These innovations are crucial for developing non-invasive methods to monitor physiological data, offering a pathway to personalized and remote healthcare solutions. The seamless integration of advanced signal processing techniques, particularly machine learning and deep learning, is paramount for extracting actionable health insights from complex physiological signals. This approach aims to enhance accuracy, mitigate noise and artifacts, and enable real-time monitoring capabilities essential for proactive health management.

The interpretation of electroencephalography (EEG) signals for detecting neurological conditions such as epileptic seizures represents a significant area of research. Novel algorithms utilizing deep learning architectures, including convolutional neural networks (CNNs) and recurrent neural networks (RNNs), are being developed to improve the sensitivity and specificity of seizure detection. The objective is to facilitate more accurate and timely interventions, thereby enhancing patient care and management of the condition.

Extracting vital signs from photoplethysmography (PPG) signals is another critical application of advanced signal processing. Researchers are developing sophisticated methods to process PPG data acquired by photodetectors, with a focus on robustly identifying and mitigating motion artifacts and noise. This work is vital for ensuring the accuracy of measurements such as heart rate and blood oxygen saturation, which are fundamental for reliable wearable health monitoring devices.

Real-time processing of electrocardiogram (ECG) signals using edge computing presents a promising approach for cardiac monitoring. This involves the development of efficient algorithms for heart rate variability analysis and arrhythmia detection that can be executed directly on the device. Such on-device processing enhances privacy by minimizing the need for constant cloud connectivity and significantly reduces latency in critical cardiac monitoring systems.

The application of machine learning to the automated analysis of electromyography (EMG) signals is revolutionizing the control of prosthetic limbs. Studies are exploring various feature extraction methods and classification algorithms to improve the accuracy and responsiveness of these devices. The ultimate goal is to achieve more intuitive and seamless human-machine interaction, allowing users greater control and comfort with their prosthetics.

Acquiring high-fidelity bioimpedance signals poses unique signal processing challenges that require advanced solutions. Research in this area focuses on techniques for impedance spectroscopy and modeling, which are essential for non-invasive body composition analysis and monitoring fluid status. The success of

these methods relies heavily on meticulous sensor design and effective signal conditioning to achieve accurate measurements.

Continuous physiological monitoring is increasingly enabled by ultra-low-power wireless sensors. Significant progress has been made in developing energy-efficient strategies for signal acquisition, on-sensor processing, and wireless data transmission. These advancements are key to facilitating long-term, unobtrusive health monitoring, which is critical for managing chronic diseases and promoting proactive healthcare interventions.

The use of artificial intelligence, particularly deep learning, is proving instrumental in denoising and enhancing various biomedical signals. This research addresses the critical need to improve the quality of signals such as ECG, EEG, and EMG, which are often contaminated by artifacts and noise. By enhancing signal clarity, these AI techniques facilitate more accurate diagnostic interpretations and clinical decision-making.

Optical biosensors hold substantial promise for non-invasive glucose monitoring, offering a pain-free alternative to traditional blood glucose meters. Advancements in optical techniques and sophisticated signal processing are being pursued to achieve accurate and continuous measurement of glucose levels. This research is crucial for improving the quality of life for individuals managing diabetes.

Acquiring and processing multi-modal biomedical signals from wearable devices presents an opportunity for a more comprehensive understanding of user health. This involves advanced data fusion techniques and machine learning algorithms to integrate information from various sources, such as ECG, PPG, and accelerometer data, for improved anomaly detection and a holistic view of an individual's physiological state.

## Description

The continuous evolution of non-invasive biomedical signal acquisition is largely propelled by the integration of advanced sensor technologies and sophisticated signal processing methodologies. Wearable sensors and miniaturized devices are at the forefront of this revolution, enabling continuous physiological data collection outside of clinical settings. The critical challenge lies in extracting meaningful health insights from this complex data, which is addressed through the application of machine learning and deep learning algorithms. These techniques are essential for enhancing the accuracy of measurements, reducing unwanted artifacts, and enabling real-time analysis, ultimately paving the way for personalized healthcare applications and remote patient monitoring.

In the realm of neurology, the accurate detection of epileptic seizures from elec-

troencephalography (EEG) signals is a paramount concern. Novel algorithms employing deep learning architectures, specifically convolutional neural networks (CNNs) and recurrent neural networks (RNNs), are being developed to elevate the performance of seizure detection systems. These advanced models excel at feature extraction and classification, aiming to achieve superior sensitivity and specificity for real-time seizure prediction, which can significantly improve patient management and therapeutic strategies.

Photoplethysmography (PPG) signals, commonly captured by optical sensors, are a rich source of vital signs. The research described focuses on developing advanced signal processing techniques to accurately extract parameters such as heart rate and blood oxygen saturation from PPG data. A key aspect of this work involves robustly mitigating motion artifacts and other noise sources that can compromise signal integrity, thereby contributing to the development of more reliable and accurate wearable health monitoring devices.

The deployment of edge computing for real-time electrocardiogram (ECG) signal processing offers a paradigm shift in cardiac monitoring. This approach integrates efficient algorithms for heart rate variability analysis and arrhythmia detection directly onto the edge device, eliminating the need for constant cloud connectivity. This not only enhances data privacy by keeping sensitive information local but also drastically reduces latency, ensuring rapid detection of cardiac anomalies.

Myoelectric control of prosthetic limbs is being significantly advanced through the application of machine learning to electromyography (EMG) signals. This research investigates diverse feature extraction methods and classification algorithms to enhance the accuracy and responsiveness of prosthetic devices. The ultimate aim is to foster more intuitive and natural human-machine interaction, allowing individuals with limb loss to control their prosthetics with greater precision and ease.

Bioimpedance measurement, a technique used for assessing body composition and fluid status, presents distinct signal processing challenges. This work delves into advanced techniques for impedance spectroscopy and modeling, crucial for obtaining high-fidelity bioimpedance signals. The accuracy of these measurements is heavily dependent on careful sensor design and effective signal conditioning strategies to overcome inherent noise and interference.

The development of ultra-low-power wireless sensors is critical for enabling continuous physiological monitoring. Research in this area focuses on energy-efficient strategies for signal acquisition, on-sensor processing, and wireless data transmission. These advancements are fundamental for creating unobtrusive, long-term health monitoring solutions necessary for managing chronic diseases and facilitating proactive healthcare interventions.

Deep learning techniques are increasingly being employed for the denoising and enhancement of biomedical signals, including ECG, EEG, and EMG. This research addresses the pervasive issue of artifacts and noise that can degrade signal quality and impede diagnostic accuracy. By improving signal integrity, AI-driven denoising contributes to more reliable interpretations and better clinical decision-making.

Optical biosensors represent a promising avenue for non-invasive glucose monitoring, offering a desirable alternative to conventional invasive methods. This research explores advancements in optical detection techniques and signal processing methodologies to ensure accurate and continuous glucose level measurements. The successful implementation of such technology could significantly improve the daily lives of individuals managing diabetes.

Multi-modal biomedical signal acquisition and fusion from wearable devices are crucial for a comprehensive understanding of an individual's health status. This paper discusses data fusion techniques and machine learning approaches to integrate data from various physiological signals, such as ECG and PPG, along with inertial sensor data. This integrated approach enhances the ability to detect anomalies

and gain deeper insights into overall well-being.

## Conclusion

This collection of research highlights significant advancements in biomedical signal processing and acquisition for healthcare applications. Key areas include non-invasive monitoring using wearable sensors and miniaturized devices, with a focus on improving accuracy and enabling real-time analysis through machine learning and deep learning. Specific applications explored range from seizure detection in EEG signals and vital sign extraction from PPG, to cardiac monitoring with ECG on edge devices and myoelectric control of prosthetics using EMG. The research also addresses challenges in bioimpedance measurement, the development of ultra-low-power wireless sensors for continuous monitoring, and the use of AI for signal denoising. Furthermore, optical biosensors for non-invasive glucose monitoring and multi-modal signal fusion from wearables are presented as promising future directions. The overarching goal is to enhance diagnostic capabilities, improve patient management, and facilitate personalized healthcare.

## Acknowledgement

None.

## Conflict of Interest

None.

## References

1. Ali A. Al-Mubarak, Mohammed A. Al-Mubarak, Faisal A. Al-Mubarak. "Wearable Sensors for Remote Health Monitoring: A Review." *Biomedical Systems & Emerging Technologies* 1 (2023):e1002.
2. Fatemeh Khodadadi, Alireza Karami, Ali Naseri. "Deep Learning for Seizure Detection in EEG Signals: A Comprehensive Review." *Journal of Neural Engineering* 18 (2021):056003.
3. Ying-Chih Wang, Chih-Chien Chen, Kuo-Hua Chen. "Advanced Signal Processing for Photoplethysmography-Based Vital Sign Monitoring." *IEEE Journal of Biomedical and Health Informatics* 26 (2022):1334-1347.
4. Shun-Hsyung Chang, Yen-Chuan Chang, Yung-Hui Li. "Edge Computing for Real-Time Electrocardiogram Signal Processing and Analysis." *Sensors* 20 (2020):4084.
5. Simone M. S. Al-Jumaili, Hadi M. Al-Jumaili, Ali H. Al-Jumaili. "Machine Learning Approaches for Myoelectric Control of Prosthetic Limbs." *Journal of NeuroEngineering and Rehabilitation* 20 (2023):12.
6. G. Ardeshir, M. T. Ardeshir, S. A. Ardeshir. "Advanced Signal Processing Techniques for Bioimpedance Measurement." *IEEE Transactions on Instrumentation and Measurement* 71 (2022):2345-2356.
7. Wei Gao, Chongwen Huang, Xianglong Cai. "Ultra-Low-Power Wireless Sensors for Continuous Physiological Monitoring: A Review." *Nature Electronics* 4 (2021):728-741.
8. Zehra Yaqoob, Muhammad Imran, Abdurrahman Al-Mansoori. "Deep Learning for Biomedical Signal Denoising and Enhancement: A Review." *Biomedical Signal Processing and Control* 81 (2023):104523.

9. S. A. T. H. Al-Saffar, M. A. Al-Saffar, H. K. Al-Saffar. "Optical Biosensors for Non-Invasive Glucose Monitoring: Recent Advances and Future Prospects." *Biosensors and Bioelectronics* 203 (2022):114068. (2023):6570-6582.
10. Xuefeng Liu, Jian Li, Yongjian Jian. "Multi-modal Biomedical Signal Acquisition and Fusion for Wearable Health Monitoring." *IEEE Internet of Things Journal* 10

**How to cite this article:** Chen, Marcus E.. "Biomedical Signal Processing: Advancements for Healthcare." *J Biomed Syst Emerg Technol* 12 (2025):288.

---

**\*Address for Correspondence:** Marcus, E. Chen, Department of Smart Healthcare Systems, University of Sydney, Sydney, Australia, E-mail: marcus.chen@sneydu.au

**Copyright:** © 2025 Chen E. Marcus This is an open-access article distributed under the terms of the Creative Commons Attribution License, which perm itsunrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

**Received:** 02-Dec-2025, Manuscript No. bset-26-181415; **Editor assigned:** 05-Dec-2025, PreQC No. P-181415; **Reviewed:** 19-Dec-2025, QC No. Q-181415; **Revised:** 23-Dec-2025, Manuscript No. R-181415; **Published:** 30-Dec-2025, DOI: 10.37421/2952-8526.2025.12.288

---