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Research Article

Design and Manufacture of a Portable EMG Device for Real-Time Acquisition and Display of Muscle Signals

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Abstract

Electromyography signals are a critical source of information for studying muscle electrical activity and play an essential role in evaluating the performance of the neuromuscular system and diagnosing related disorders. However, their high sensitivity to environmental noise such as power line interference, motion artifacts, and electromagnetic disturbances highlights the pressing need for precise design in signal processing and recording systems. This paper presents a compact, portable system, specifically developed for the acquisition and processing of muscle signals. The system incorporates advanced filtering stages with precise cutoff frequencies and robust signal amplification to deliver high-quality signals. After amplification and filtering, the signals are sampled using a 12-bit ADC and wirelessly transmitted via a module to a web application. This enables real-time visualization of raw signals, rectified signals, and average peak values. The results show that the system's frequency response is well-aligned with the requirements of muscle signals, significantly reducing interfering frequency noise. Furthermore, the higher resolution of the ADC and the implementation of high-order filters have markedly improved system performance. By integrating a right-leg drive circuit, the system has successfully increased the signal-to-noise ratio from 18.19 dB to 43.52 dB. A performance comparison with existing commercial devices underscores the significant advantages of this system in terms of signal-to-noise ratio, accuracy, and portability. The device has a wide range of applications, including diagnosing neuromuscular disorders, controlling robotic prostheses, and analyzing movement. Regarding its connectivity to smartphones or computers, it provides an ideal infrastructure for developing advanced rehabilitation and biomechanical systems.

Keywords: Electromyography (EMG); signal amplifier; portable system; diagnosis of neuromuscular disorders

Highlights

- Design of a portable EMG system with advanced noise-reduction techniques.
- Implementation of high-order analog filters and right-leg drive circuit for SNR improvement.
- Real-time signal visualization via a web application using ESP32 wireless communication.

Citation: [in Persian]

1. Introduction

Electromyography (EMG) is a vital biomedical technique for recording and analyzing electrical signals generated by muscle activity. This method is extensively utilized in diagnosing neuromuscular disorders, controlling bionic prosthetics, and conducting biomechanical motion analysis [1]. However, commercial EMG devices often encounter challenges such as high costs, limited portability, and susceptibility to environmental noise, including 50 Hz power line interference and motion artifacts [2]. In recent years, significant research efforts have focused on enhancing system performance through optimized amplifier circuits, analog/digital filtering, and advanced signal-processing techniques [3]. One of the most critical limiting factors in EMG systems is common-mode noise, which can infiltrate the signal from the environment or electrodes. Previous studies have shown that "right-leg drive" circuits effectively suppress this noise. For instance, article [4] employed a digital notch filter to eliminate 50 Hz noise; however, it required expensive equipment and introduced computational complexity. In contrast, simpler analog filter designs, such as higher-order filters, are more feasible for low-cost systems [5]. he accuracy of EMG systems is also influenced by the resolution of the analog-to-digital converter (ADC) and the sampling frequency. Studies indicate that a 12-bit ADC with a 2 kHz sampling rate, as utilized in the proposed system, provides superior signal fidelity compared to commercial devices equipped with 10-bit ADCs (e.g., MyoWare, BITalino [6]). For example, a 12-bit ADC offers 4,096 distinct digital levels, allowing for precise capture of subtle muscle signal variations that are often lost in lower-resolution systems. This paper introduces a portable, cost-effective EMG device designed to address these limitations.

2. Innovation and contributions

In this paper, a novel portable EMG system is proposed, featuring:

1. High-Order Filtering: A fourth-order high-pass and sixth-order low-pass filter cascade to suppress low- and high-frequency noise while preserving EMG bandwidth (10–500 Hz).
2. Right-Leg Drive Circuit: Reduces common-mode noise by injecting an inverse signal, boosting SNR from 18.19 dB to 43.52 dB.
3. Wireless Real-Time Monitoring: ESP32 module transmits processed EMG data to a web application, enabling live visualization of raw, rectified, and peak-averaged signals.
4. Digital Gain Adjustment: A programmable potentiometer (MCP4161) automates gain calibration based on signal amplitude, ensuring adaptability to skin thickness and sweat variations.

Among the innovations of this paper, the following can be stated:

- Integration of a Twin-T notch filter and Salen-Key topology for precise frequency-selective noise elimination.
- Validation through MATLAB signal processing (RMS, FFT) and comparison with commercial systems (BITalino, MyoWare), demonstrating superior noise rejection.
- Open-source hardware design for scalable applications in rehabilitation and biomechanics.

3. Materials and Methods

The system comprises analog preprocessing (filtering and amplification), ADC conversion, and wireless data transmission. EMG signals are acquired via gel electrodes and amplified using an AD620 instrumentation amplifier. Noise is reduced in three stages: (1) 50 Hz notch filter, (2) fourth-order high-pass filter (10.7 Hz cutoff), and (3) sixth-order low-pass filter (1 kHz cutoff). The right-leg drive circuit injects inverse common-mode noise. A 12-bit ADC digitizes signals, which are transmitted via ESP32 to a web application for real-time display. Signal processing (rectification, peak averaging) is implemented in firmware, while MATLAB validates spectral and temporal features

4. Results and Discussion

The system demonstrated an improvement in Signal-to-Noise Ratio (SNR) compared to existing designs, achieving effective noise suppression at 50 Hz (attenuation: -40 dB) while maintaining minimal phase distortion (see Fig. 5–7). Comparative tests (see Fig. 15) revealed clearer phases of muscle activation during the right-leg drive, effectively reducing baseline drift. The 12-bit Analog-to-Digital Converter (ADC) facilitated the detection of subtle variations in electromyography (EMG), covering a range of 40 μV to 1 mV, and outperformed 10-bit commercial systems. Wireless latency was maintained below 200 ms, making it suitable for real-time applications. Fast Fourier Transform (FFT) analysis confirmed the presence of dominant EMG frequencies ranging from 30 to 400 Hz, consistent with physiological muscle contractions. The system's compact design (98 × 60 mm) and automated gain adjustment through a digital potentiometer (MCP4161) enhance its usability across various physiological conditions, such as differing skin thicknesses or sweat levels. Its modular architecture allows for future scalability, including multi-channel expansion and the integration of machine learning for automated signal interpretation.

5. Conclusion

This portable EMG system addresses critical limitations through advanced filtering, right-leg drive noise cancellation, and real-time web visualization. Its high-resolution signal acquisition and open-source design offer scalable solutions for neuromuscular diagnostics and prosthetic control. Future work includes machine learning integration for automated signal analysis.

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Author Contributions:

Hajar Danesh: Conceptualization, theory development, project supervision, simulation execution, construction and manuscript writing. **Seyed Hasan Mirmahdi**: Simulation execution, construction, and manuscript writing. **Hamidreza Shirzadfar:** Verification of analytical methods and manuscript editing. **Farhad Khosravi:** Verification of analytical methods and manuscript editing**.**